Effects of Seeding Isolated Cumulus Clouds with Silver Iodide

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ABSTRACT

Isolated cumulus clouds with supercooled tops were seeded from an aircraft. Either a large (20 gm), small (0.2 gm) or zero quantity of silver iodide was used, with random choice of treatment. The amount of rain which fell from the cloud was measured at cloud base by means of an impactor on the seeding aircraft.

Clouds with tops −10C or colder which were treated with the larger quantity of silver iodide yielded significantly more rain than similar, untreated clouds. The mean rainfall from clouds seeded with the reduced treatment was also higher than that from the unseeded clouds, but the margin in this case was insufficient to demonstrate the statistical significance of the result.

1. Introduction

In recent years the objective of most cloud seeding experiments has been to detect changes, caused by seeding, in the rainfall of an area. A second type of experiment, in which the effects of seeding a single cloud are studied, has received less attention. Examples of this type, with varying detailed objectives, have been reported by Vonnegut and Maynard (1952), Warner and Twomey (1956) and Malkus and Simpson (1964).

These experiments provided valuable evidence of the effects of silver iodide released from an aircraft in modifying individual cumulus clouds. However, a great deal more information is needed, in quantitative and statistically acceptable form, particularly concerning aspects such as:

a) The optimum seeding rate in terms of a stated objective.
b) The effect of conditions such as the cloud top temperature.
c) The amount of rainfall following seeding.

The report presents the results of a series of experiments in which an aircraft was used to seed isolated cumulus clouds with silver iodide smoke and to measure the rain which fell from them. The experiments were randomized and the objectives were 1) to provide statistically acceptable evidence of the effect of seeding on the amount of rain which fell from the clouds under various conditions, and 2) to ascertain the effects of varying the quantity of silver iodide used.

2. Experimental arrangements

a) Design of experiments. An aircraft was equipped to seed clouds with one of two quantities of silver-iodide smoke, and to measure the rain which fell from the seeded cloud. It carried a crew of three; a pilot, an experimenter who selected a cloud, and a 'randomizer' who applied one of the two possible treatments or no treatment, according to a random series, but did not inform the experimenter. The subsequent behavior of the cloud was observed and any rain which fell from it was measured. Only when the measurements and all calculations and records were complete was the experimenter advised which burner had been used. The experiments were all conducted over land within 1800 (and usually 1000) km of Sydney.

The experimental design continued in the same form throughout except for one change (see Section 5) after the first 52 clouds, i.e., after 22 October 1964. After this, the smaller burner was not used. The random series was continued without alteration, however, so that when the series indicated that the larger burner or no burner should be used the experiment continued as before, but when it indicated that the smaller burner should be used, the cloud concerned was used for other observations, not described in this report.

b) Specification of suitable clouds. A cloud was regarded as suitable for treatment if it met the following specifications:

(i) The temperature of the free air near to and level with the cloud top was −5C or colder.

(ii) From observation of this and other clouds, the experimenter believed that the temperature of the cloud top was likely to be −5C or colder for more than 30 min.

(iii) The depth of the cloud exceeded half the terrain clearance of the base and also exceeded 1000 m.

(iv) The height of the cloud base did not exceed 3500 m.

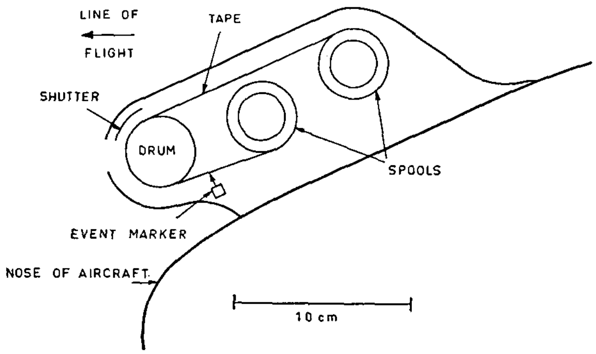

FIG. 1. Raindrop impactor.

(v) The cloud development was substantially vertical, with the top mostly over the base. Excessive shear was unacceptable.

(vi) The cloud shape was typically cumuliform with flat and substantial base. Clouds with large tops and small or ragged bases were unacceptable.

(vii) The cloud was reasonably isolated, and did not touch others of size comparable to itself.

(viii) The cloud was dense and compact. Tenuous or transparent composition was unacceptable.

(ix) No visible rain fell from the cloud prior to treatment.

(x) No visible rain fell from other clouds within 30 km prior to treatment.

(xi) Prior to treatment the subject cloud exhibited no visible signs of glaciation and was not within 30 km of another cloud which did.

c) Sequence of events in a typical flight. The aircraft proceeded to an area where suitable clouds were forecast. When potentially suitable clouds were encountered the aircraft climbed to the level of the cloud tops, or to 5000–6000 m (the maximum altitude it could reasonably reach) if the clouds were higher. The temperature of the free air level with the cloud tops was measured, or the height and temperature estimated (Section 3). Other cloud characteristics such as shear and durability were noted.

When a cloud was found which appeared to be suitable for seeding it was photographed, the top height and temperature were measured or estimated and the aircraft descended rapidly to the cloud base. If observation from the base confirmed that the specification was satisfied, the experimenter declared the cloud selected for experiment. The randomizer then opened the next envelope of a series containing instructions as to the treatment to be used, and operated the seeding equipment accordingly while the aircraft made two passes under the cloud. The experimenter could not see what the randomizer was doing and had no means of knowing which burner was used. The total elapsed time between the selection of the cloud while the aircraft was near the top and completion of seeding was about five minutes.

After the cloud had been seeded, the aircraft flew at cloud-base level in a predetermined pattern, passing repeatedly through the same air position under the cloud, while measurements of rain were made with an impactor. Between passes the aircraft departed 10 km from the center of the cloud base. This enabled photographs of the cloud to be taken from known positions, giving a measure of cloud top height, and also enabled the experimenter to observe whether adjacent clouds were raining or glaciated. This flight pattern was continued as long as the cloud was recognizable.

On two occasions when snow fell from the cloud base the aircraft flew below the melting level, which was up to 300 m below the cloud base, in order to enable the impactor to measure rain.

d) Seeding technique. The aircraft was equipped with two ice nucleus generators in which acetone solutions of silver iodide and sodium iodide were burnt. One was the type used in the Australian cloud-seeding experiments (Smith *et al.*, 1966). It consumes 0.15 gm sec^{-1} and its output is 3×10^{13} nuclei sec^{-1} active at -17C and 1.5×10^{11} active at -10C. The other generator was mechanically identical but the concentrations of silver and sodium iodides in the solution were reduced by a factor of 100; its nucleus output was measured and also found to be reduced by a factor of 100. Each cloud was seeded at the base for approximately 2 min; thus, the amount of silver iodide burnt per cloud was 20 or 0.2 gm for the two burners, which are referred to as the "larger" and "smaller" burners.

A similar flight path was used for all experiments regardless of the type of burner (if any). In a typical case the aircraft flew at cloud base level, and passed across a diameter which included the densest part of the base, turned to follow somewhat inside the circumference, then passed along a second diameter approximately perpendicular to the first, again traversing the densest part of the base. Considerable updrafts could usually be felt during parts of this manoeuvre.

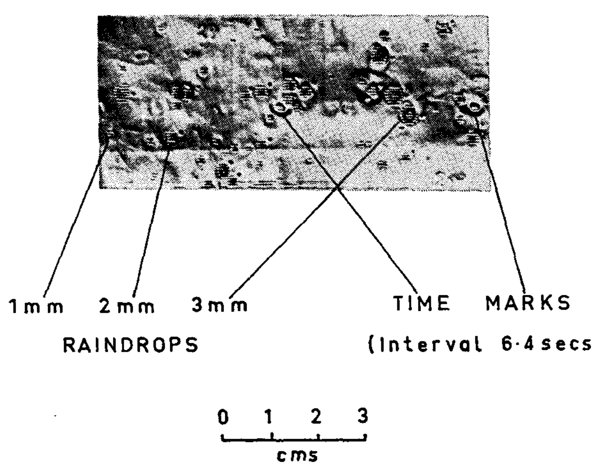

FIG. 2. Sample tape from impactor.

e) *Measurement of rain.* Measurements of rain through which the aircraft flew were made with an impactor fitted to the nose of the aircraft. The instrument used for the first eight clouds was based on a design by M. P. Garrod of the Meteorological Research Flight, Farnborough, England. Raindrops made permanent impressions on a strip of aluminum tape which moved at a speed of 1.25 cm sec^{-1} past an aperture 2.5 cm square. The impactor employed in subsequent experiments (Fig. 1) was similar in principle, but when operating, a shutter uncovered the aperture automatically for 0.4 sec every 6.4 sec., or in light rain it could be left open. The aperture was 3.8 cm square and the tape speed was 0.74 cm sec^{-1}. There was a timing marker which could also be operated as an event marker. A sample tape with raindrop impressions is illustrated in Fig. 2. The ratio of imprint diameter to drop diameter was calibrated on a whirling arm at aircraft speed and found to be 1.3 for drops of diameter 1 to 3 mm, rising to 1.5 for drops of 5 mm diameter.

The aircraft flew under the cloud at 8-min intervals, flying each time at 90° to the previous pass. The flight pattern was adjusted, if wind shear made it necessary, to ensure that the aircraft continued to fly under the densest part of the cloud and through the rain, if any. The impactor was operated, giving the intensity and linear dimensions of the rain along the orthogonal flight paths. These dimensions were plotted against time, and the area of the shower and its variation with time were computed assuming the shower to be elliptical. If it was known from observations or photographs that it was not elliptical, an arbitrary correction was introduced by the experimenter before he knew which burner had been used. The rate of flow of precipitation from the cloud was determined, plotted against time and numerically integrated, giving a measurement of the total volume of rain. An example is given as Fig. 3.

A considerable fraction of the rain could usually be seen to reach the ground. No attempt was made to measure the rainfall at ground level, but calculations based on those of Best (1952) suggest that it would usually have exceeded half that at cloud base on most occasions when the total precipitation was greater than a few thousand cubic meters.

f) *Classification of clouds by top temperature.* When clouds are seeded with silver-iodide smoke the number of ice crystals which can be produced depends on the temperature at which the nucleation takes place, the number decreasing by a factor of 100 between −15 and −10C, and very rapidly at warmer temperatures. In investigating the effects of a given quantity of silver iodide, or in comparing the effects of two different quantities, it is therefore desirable to consider the results in relation to cloud-top temperature.

Clouds were divided into two classes according to the following convention. If, at any time during the time interval from five minutes before seeding to ten minutes after seeding, the cloud-top temperature is known

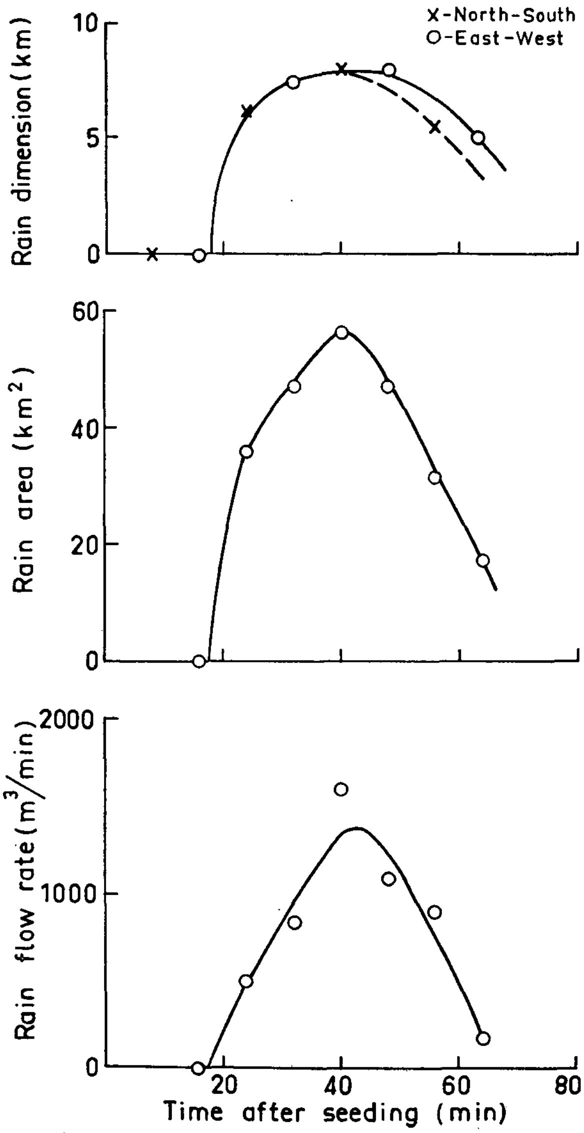

Fig. 3. Sample rain measurement on 20 June 1964. Total rain amounted to 4×10^4 m^3.

to have fallen to −10C or below, the cloud was classified as "−10C or colder." Other clouds were classified "warmer than −10C."

3. Summary of data obtained

A total of 73 clouds, which fulfilled the specification given in Section 2(b), were selected for experiment. Four of them merged with other clouds and lost their recognizable identity within 30 min; these have been rejected from analysis. Data for the remaining 69 clouds are given in Table 1. The amount of silver iodide with which each cloud was treated is given in column 2.

Clouds were encountered in a variety of meteorological situations, which have been classified into five groups: (i) Pre-frontal; (ii) Frontal; (iii) Post-frontal;

TABLE 1. Details of experiments.

			Cloud top							
Date	Treatment AgI (gm)	Synoptic type	Temperature 5 min before treatment (°C)	Estimated accuracy (°C)	Temperature 10 min after treatment (°C)	Height above sea level (km)	Cloud depth (km)	Life after seeding (min)	Adjacent rain	Total rainfall $m^3 \times 1000$
9/10/62	20	5	−12	5	−10	7.9	5.0	75	No	130
9/10/62	0	5	−10	5	−6	6.2	4.0	35	No	Nil
20/10/62	0	1	−7	3	+2	5.5	3.9	33	No	Nil
20/10/62	0.2	1	−6	3	−3	5.2	3.0	20	No	Nil
23/10/62	0	1	−8	3	−7	5.8	2.4	40	No	Nil
23/10/62	0.2	1	−16	5	−9	6.7	3.7	33	No	Nil
10/12/62	0	5	−13	4	−14	7.2	4.0	58	No	10
8/ 2/63	0.2	4	−5	2		5.6	3.1	<16	No	<1
8/ 2/63	0	4	−6	3	−11	6.4	3.7	51	No	<1
8/ 2/63	20	4	−10	4	−13	7.0	4.7	>70	No	390
10/ 4/63	0	2	−11	3	−8	5.6	4.0	30	No	72
25/ 4/63	0	1	−8	1	−4	4.7	2.7	<16	No	Nil
2/ 5/63	0	3	−8	1	−7	4.3	3.3	50	No	20
4/ 5/63	0.2	2	−7	1		4.3	3.3	60	No	70
4/ 5/63	0	2	−9	1	−5	4.7	3.2	>120	No	630
24/ 6/63	0	4	−8	2	−5	3.8	2.1	40	No	Nil
25/ 6/63	0.2	4	−13	3	−11	4.7	3.3	>140	No	880
14/ 8/63	0.2	1	−10	2		4.0	2.7	<15	No	Nil
15/ 8/63	20	1	−14	4	−11	5.3	4.1	50	No	690
27/ 8/63	20	4	−8	1	−8	3.5	1.8	15	No	Nil
11/10/63	0.2	1	−13	2	−14	5.2	3.0	35	No	Nil
11/10/63	20	1	−12	2	−13	5.0	2.0	30	No	Nil
6/ 5/64	20	2	−5	1	−14	3.4	3.3	>150	No	850
7/ 5/64	0.2	2	−6	1		3.4	2.2	45	No	Nil
7/ 5/64	0	2	−11	1	−14	4.1	2.7	30	No	Nil
8/ 5/64	0.2	2	−9	1	−10	4.6	3.3	48	No	2
9/ 6/64	20	2	−8	1		3.2	2.1	24	No	Nil
20/ 6/64	20	1	−7	1		3.0	1.5	56	No	Nil
20/ 6/64	0.2	1	−11	1		3.5	1.7	64	No	40
12/ 7/64	20	3	−6	1		3.1	1.5	20	No	Nil
13/ 7/64	0.2	3	−7	3	−12	4.4	2.6	>104	No	330
20/ 7/64	20	3	−6	1	−6	2.7	1.1	25	No	Nil
23/ 7/64	0	1	−10	1	−6	3.5	2.0	12	No	Nil
9/ 8/64	0.2	3	−8	1	−9	3.0	1.0	31	No	Nil
9/ 8/64	0	3	−9	1	−9	2.9	0.8	50	No	Nil
11/ 8/64	0	3	−8	1	−9	2.6	1.7	60	No	Nil
11/ 8/64	20	3	−11	1	−13	2.8	1.8	>95	No	110
11/ 8/64	0	3	−12	1	−14	3.0	1.4	>30	No	Nil
27/ 8/64	0.2	2	−15	2	−15	4.4	2.2	100	No	27
27/ 8/64	0.2	2	−20	4	−17	5.2	3.0	64	No	<1
16/ 9/64	20	3	−6	1	−4	3.4	2.4	70	No	4
22/10/64	0.2	1	−7	1	−2	4.5	1.5	<12	No	Nil
22/10/64	0	1	−8	1		4.4	1.5	24	No	Nil
27/10/64	0	2	−18	3	−20	4.9	3.2	114	No	210
9/11/64	0	2	−15	3	−20	5.1	3.3	70	No	Nil
9/11/64	0	2	−14	2	−11	5.0	2.6	85	No	Nil
11/11/64	20	2	−20	4	−20	6.4	4.0	120	No	850
11/11/64	0	2	−12	4	−17	5.2	2.2	80	No	210
12/ 1/65	0	3	−5	1	−5	4.6	3.0	58	No	Nil
19/ 1/65	20	1	−8	3	−8	5.5	2.5	50	No	Nil
19/ 1/65	20	1	−13	5	−25	6.1	2.8	28	No	Nil
20/ 1/65	20	1	−12	6	−20	6.1	3.5	60	No	23
21/ 1/65	0	3	−7	3	−8	5.2	3.0	70	No	9
26/ 1/65	0	2	−20	3	−20	6.6	4.0	35	No	4
26/ 1/65	20	2	−12	3	−21	5.5	2.9	55	No	22
27/ 1/65	0	5	−9	2	−9	5.5	3.6	37	No	Nil
24/ 2/65	20	2	−11	4		5.8	3.8	20	No	Nil
19/12/62	0.2	5	−11	2		6.1	3.7	54	Yes	26
24/ 6/63	20	4	−9	2	−11	4.4	3.0	56	Yes	29
2/ 7/63	0	4	−8	1		3.0	2.2	35	Yes	Nil
14/ 8/63	0	1	−12	3		4.3	3.2	40	Yes	22
23/ 9/63	0	3	−7	1	−5	4.9	3.6	70	Yes	Nil
17/12/63	0	3	−11	3	−11	5.8	3.8	32	Yes	Nil
8/ 5/64	20	2	−10	2		4.6	3.3	48	Yes	32
12/ 7/64	0	3	−11	1	−14	3.7	2.5	60	Yes	130
16/ 9/64	0	3	−14	1	−14	3.8	2.4	>60	Yes	70
23/10/64	0	4	−7	1	−9	3.0	1.6	40	Yes	Nil
27/10/64	0	2	−15	2	−10	5.0	3.0	24	Yes	Nil
17/ 2/65	0	1	−21	4	−20	6.7	3.4	50	Yes	83

(iv) Air mass, remote from front; (v) Tropical trough. The classifications are indicated in column 3 of Table 1. The first four groups all refer to situations in which general advection from the west is usual. The 'tropical trough' group refers to a situation frequent in Queensland, in which moist air from the east moves inland at low levels, below the prevailing upper level westerlies. Almost all cases were dependent to some extent upon diurnal heating, and many clouds in all categories may have been affected by some degree of orographic influence. One air-mass cloud (25 June 1963) occurred over an isolated mountain.

Inspection of the figures does not suggest any difference in the results of seeding in the various synoptic situations. Most of the heaviest rainfalls occurred in frontal conditions, particularly in the case of unseeded clouds. The numbers of cases are not sufficient to justify more serious analysis of the results in different categories.

The cloud-top temperature, quoted in column 4, was measured or estimated about five minutes before seeding. An estimate of the accuracy of this measurement is given in column 5, using an arbitrary convention of ±1C if the aircraft was level with the cloud top, but if the aircraft could not reach the cloud top, the height excess was estimated and the temperature sounding extrapolated at 1C per 150 m, and ±0.5C was added to the error estimate for each 300-m height difference between the aircraft and the cloud top.

The cloud-top height at intervals after seeding was determined when possible from photographs (Section 4) and plotted against time for each cloud. The height 10 min after seeding was taken from this curve, and corresponding temperature, estimated from the actual or extrapolated aircraft sounding, is given in column 6. In the case of 14 clouds, no photographs, and hence no height measurements after seeding, were available and no figure appears in column 6. These clouds were nevertheless classified by the same criterion. This leads to doubt in three cases. The first cloud on 7 May 1964 and that on 9 June 1964 had tops warmer than −10C before seeding, and no information is available as to their temperature after seeding; the classification of these two clouds could change if their tops subsequently rose. A case could be made for omitting them on grounds of inadequate information, but they have been included. The first cloud on 4 May 1963 was observed to glaciate, and the top temperature, 10 min after seeding, may have been colder than −10C; however, in the absence of a measurement to that effect, it has been classified, according to the convention, as warmer than −10C. The temperature classification of the other 11 clouds without photographs would not have been affected by the temperature 10 min after seeding; five were −10C or colder before seeding, three were observed to subside within 15 min, and three were inversion limited and their height is likely to have remained constant.

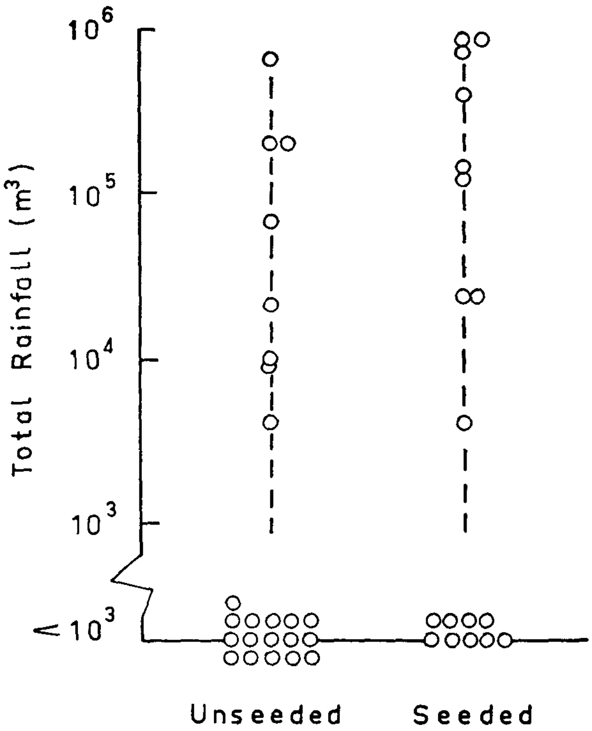

Fig. 4. Total rainfall from clouds with no adjacent rain. Larger burner.

The cloud-top height and depth, given in columns 7 and 8, were measured or estimated about 5 min before seeding.

Column 9 shows the life of the cloud from the time of seeding (or in the case of the unseeded clouds, from the time when the aircraft flew, as if seeding, under the clouds) until the cloud lost its recognizable identity, usually by evaporating or subsiding. The total life would have been greater than that stated, as the lifetime before seeding was not measured. In cases where a given life is said to have been exceeded, the aircraft had to leave the cloud while it was still recognizable.

The last 12 clouds in Table 1 have been treated separately in the analysis. In these cases, rain fell within 30 min of seeding from other clouds within 30 km of the treated cloud, with intensity estimated as exceeding a 'light shower.' If clouds within 30 km from the seeded cloud had shown visible signs of glaciation within 30 min after seeding, the clouds would also have been analyzed separately, but no such case occurred.

4. Results with larger burner

a) Clouds with no adjacent rain.

(i) Rainfall. Eighteen clouds with no adjacent rain were seeded with the larger burner and 24 were unseeded. The rainfall for the two groups of clouds is given in Fig. 4, and when separated by cloud top temperature, in Fig. 5.

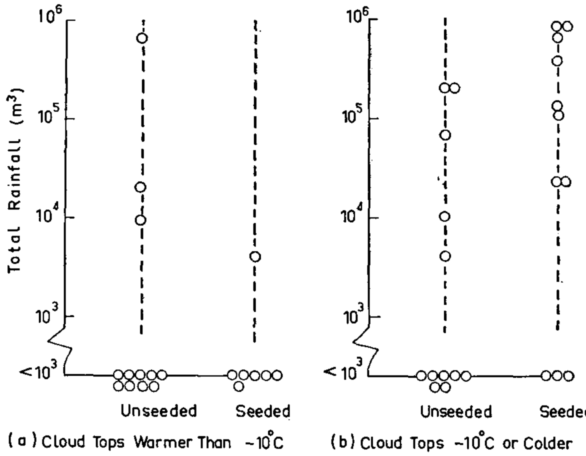

FIG. 5. Total rainfall from clouds with no adjacent rain, separated by cloud top temperature. Larger burner.

Mean and median rainfalls for the seeded and unseeded clouds, and for the same groups separated by temperature, are given in Table 2. They must be considered with due regard to the small numbers and the wide scatter of the values.

Both the mean rainfall and the proportion of clouds with heavy rainfall were higher for the seeded than for the unseeded clouds. These features were even more conspicuous with the colder clouds. No rain fell from most of the clouds with warmer tops. Fewer of the seeded than the unseeded clouds in the warmer category rained, but the numbers are too small for any conclusions to be drawn. The mean rainfall of 6×10^4 m^3 for unseeded warmer clouds mainly reflects one cloud (4 May 1963, second cloud) which had an unusually long life during the latter part of which the top was colder than $-10C$.

In Fig. 6 the mean rainfall per cloud is plotted against cloud top temperature, for seeded and unseeded clouds. Means were taken for all clouds within temperature bands of -5 to $-9C$, -10 to $-14C$ and $-15C$ and colder. Separation into such small groups would be better attempted with more data, but the figure suggests little effect (negative, if anything) from seeding clouds with tops warmer than about $-8C$, pronounced effects with cloud tops from about -10 to $-15C$ and reduced effects at colder temperatures. At temperatures below $-15C$, the average rainfall from unseeded clouds increases as might be expected, but that from seeded clouds appears to decrease, though possibly not to a significant extent.

TABLE 2. Rainfall per cloud in m^3 for clouds with no adjacent rain. Larger burner.

	Seeded		Unseeded	
	Mean	Median	Mean	Median
All clouds	2×10^5	$\sim10^3$	5×10^4	$<10^3$
Clouds with tops warmer than $-10C$	10^3	$<10^3$	6×10^4	$<10^3$
Clouds with tops $-10C$ or colder	3×10^5	10^5	4×10^4	$<10^3$

Statistical tests were applied to the rainfall figures, testing the null hypothesis that seeding had no effect. A computer was used to determine the chance of the mean rainfall of the seeded clouds being as high as or higher than that observed if the seeded clouds were chosen at random from all the clouds, giving a significance level of 0.05. The same test applied to clouds with tops $-10C$ or colder gave a significance level of 0.02, both one-sided. Mann and Whitney tests on the ranks of the rainfall gave significance levels of 0.08 and 0.03, respectively.

These data support a conclusion that seeding with 20 gm silver iodide per cloud increased rainfall from clouds whose tops were $-10C$ or colder when there was no adjacent rain.

(ii) Lifetime. The median lifetime of seeded clouds, with tops $-10C$ or colder and with no adjacent rain, was 60 min while that of similar but unseeded clouds was 40 min. A Mann and Whitney test was applied to the ranks of the seeded and unseeded lifetimes, with null hypotheses that the seeding had no effect. It was arbitrarily assumed that when the life was given as "more than a certain value" it exceeded it by 15 min. The one-sided significance level was 0.2.

It seems possible that the seeding may have prolonged the life of these clouds but a conclusion to that effect would not be justified.

There was no appreciable difference between the lifetimes of seeded and unseeded clouds with tops warmer than $-10C$.

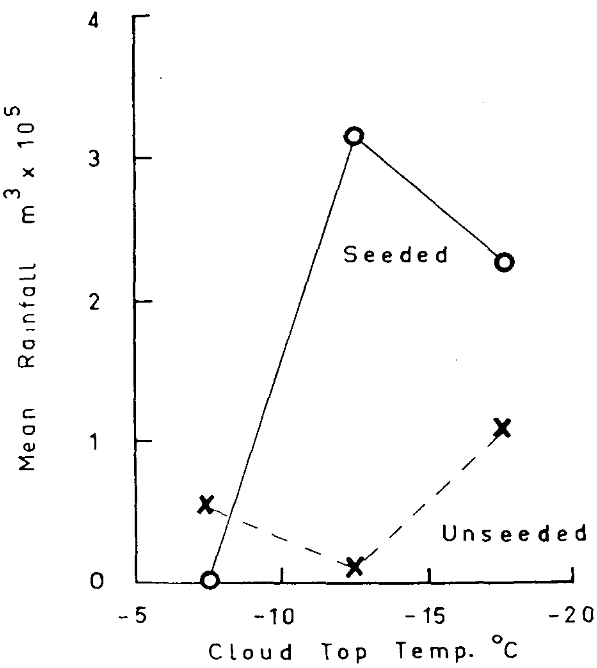

FIG. 6. Variation of mean rainfall per cloud with cloud top temperature. Larger burner.

(iii) Changes of cloud-top height with time. If seeding with silver iodide causes glaciation in the cloud top it would be expected to increase the buoyancy and hence the height of the cloud top. In some atmospheric conditions the expected increase of height might be several thousand feet (Woodley, 1964). Cases in which this was observed have been reported by Kraus and Squires (1947) and by Malkus and Simpson (1964).

In the present experiments, approximate measurements of the heights of cloud after seeding were derived from photographs (Section 2). These were taken at intervals of about 8 min, and about half of them were selected as the most suitable for height measurements. In seven cases, these were supplemented by direct measurement of height from the aircraft near the end of the cloud life. A curve of height against time was drawn for each cloud; the mean departure of the measurements from the curves was about 150 m but, of course, the uncertainty of the height is greater.

Most of the clouds maintained a roughly constant height for about half their life and then gradually subsided. The curves for clouds with no adjacent rain and with tops −10C or colder exhibited only minor differences in the maximum height reached by seeded and unseeded clouds, but the seeded ones tended to maintain their height for a longer time. Two of the seeded and two of the unseeded clouds increased in height by 500 m or more after seeding and before subsiding, but there was no case, either seeded or unseeded, of growth by many thousands of meters.

It can be concluded that the effects of the seeding on the height of the cloud tops were not very great, and, as far as can be judged from these measurements, took the form of an increase in the time for which the height was maintained rather than a change in the maximum height reached.

The meteorological conditions may have been different in cases where spectacular growth was reported, or the difference may be associated with the difference in seeding methods. Malkus and Simpson used several kg of silver iodide per cloud while Kraus and Squires used about 300 kg of dry ice, and in both cases the seeding materials were dropped into the cloud from above.

b) Clouds with adjacent rain. During the last 12 experiments in Table 1, rain fell from clouds nearby (Section 3). In these conditions, rain only fell when the cloud-top temperature was −10C or colder, and there is no evidence that either the rain or the lifetime of the clouds was influenced by the seeding. The number of unseeded clouds was nine while only two were seeded with the larger burner; these numbers are too small to enable any conclusions to be drawn.

5. Results with smaller burner

The seeding technique with a reduced quantity of 0.2 gm of silver iodide per cloud (smaller burner) was used, as mentioned in Section 2, during the period from the beginning of the series up to October 1964. The results may be compared with those using other techniques during the same period.

The mean rainfall during this period was 5×10^4 m^3 for the untreated clouds, 9×10^4 m^3 for clouds seeded with the smaller burner and 2×10^5 m^3 for clouds seeded with the larger burner. When clouds seeded with the smaller burner were separated by temperature, the mean rainfall from those with tops −10C or colder was 1.4×10^5 m^3 and for warmer clouds 10^4 m^3. Mann and Whitney tests were applied to the ranks of the rainfalls from unseeded clouds and those seeded with the smaller burner. The significance level was 0.2 both for all the clouds and for those with tops −10C or colder.

The results at this stage were consistent with seeding using the smaller burner having caused an increase in rainfall which was less than that apparently caused by the larger burner. However, it was concluded that it was unlikely that an increase in rainfall due to seeding with the smaller burner would become statistically significant in a series of experiments of reasonable length, and this type of seeding was accordingly not continued.

No change associated with the smaller burner could be detected in the lifetime or the height of the tops of these clouds.

6. Summary of results

When cloud top temperatures were warmer than −10C, or when rain fell within 30 km of the seeded clouds, no effects of seeding were detected.

When cloud top temperatures were −10C or colder, and their was no adjacent rain:

1) Clouds seeded with the smaller burner yielded more rain than unseeded clouds but the difference was not statistically significant.

2) The lifetime of clouds seeded with the larger burner exceeded that of unseeded clouds but again the difference was not significant.

3) Seeding does not appear to have greatly affected the maximum height reached by the cloud tops but may have caused them to maintain their height for a longer time.

4) The mean rainfall from clouds seeded with the larger burner was several times greater than that from unseeded clouds, the difference was statistically significant and the conclusion is drawn that seeding increased the rainfall.

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