The Use of Silver Iodide for Seeding Individual Clouds

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Abstract

The results of seeding thirty-five supercooled clouds, mostly cumuliform, are described. The silver iodide was released as a smoke from aircraft flying through the upper levels of the cloud or just below cloud base. It is concluded that silver iodide is an effective agent in inducing precipitation in clouds whose upper levels are at temperatures colder than —5° C, and that the precipitation is usually released 20 to 25 minutes after seeding in the case of cumulus clouds but later in the case of layer clouds.

1. Introduction

Although the effectiveness of silver iodide as a nucleus for ice crystal formation, and consequently its value for cloud seeding, was first reported by Vonnegut in 1947 there is still quite inadequate documentation of its effectiveness in releasing precipitation from individual clouds. Indeed most of the literature on the use of silver iodide for cloud seeding relates to experiments in which the material has been released as a smoke from the ground in an attempt to influence the rainfall over a comparatively large target area downwind from the ground generator. Decisions about the effectiveness of the seeding have been based largely on a statistical analysis of the rainfall distribution, both in time and space, and considerable doubt exists amongst meteorologists about the validity of many of the conclusions reached. Comparatively few aircraft experiments have been reported, and most of these have also been aimed primarily at seeding a target area; little attention has been paid apparently to observations of the growth and development of the seeded clouds, results being assessed as before by a statistical analysis of rainfall.[1]

This paper presents the results of some thirty-five aircraft experiments in seeding individual clouds in which the cloud was kept under observation for at least 30 minutes, and often for up to 60 minutes after being seeded, and its development compared with that of its unseeded neighbours. The data presented demonstrate fairly conclusively the effectiveness of silver iodide as a seeding agent in the field, and confirm much laboratory experience about its action. For the most part the experiments were made in relatively isolated cumulus clouds located in southeastern New South Wales about 100 miles inland from the coast; a lesser number of experiments was made in inland South Australia and North Queens-

[1] At a conference on weather modification studies held at the University of Arizona in April 1956 aufm. Kampe, Kelly and Weickmann (private communication) reported the results of seeding supercooled stratus clouds. These experiments were aimed, however, at clearing thin cloud layers rather than releasing precipitation.

land, and only very few experiments have been made in maritime conditions near the coast.

2. Method of feeding

(a) *Flight procedure*

Three different aircraft were used in these seeding experiments: an Auster, an Anson and a DC3. The first two aircraft were not fitted for instrument flight in cloud and seedings with them were made just below cloud base. Thereafter the aircraft stayed in the vicinity for half to one hour while the cloud was kept under observation. The DC3 aircraft was fully instrumented and nearly all seedings made with it were at a level, usually near the cloud tops, at the temperature where silver iodide was considered to be immediately active as an ice nucleus. Since the aircraft was also fitted with radar the presence of precipitation in the cloud could be observed well before it had reached the base. Observations of the results of seeding were made both at the seeding level inside the cloud and from below cloud base.

For the most part seedings were made only when favourable experimental conditions were known to exist: that is, when cloud top temperature was known or expected to be -4° C or colder and the cloud was not already precipitating, surrounding clouds were not already raining, and the chosen cloud appeared to be durable. Wherever possible a control cloud or clouds in the vicinity of the seeded one, and of equal or greater initial development, was also kept under observation for the full period of the experiment.

(b) *Generation of silver iodide nuclei*

In the case of the Auster aircraft, nuclei were generated by injecting an acetone solution of silver iodide into the engine exhaust. A small hand-operated pump injected roughly 5 cc of solution at a time, and usually a total of 50 to 100 cc, containing about 10 gm of AgI was used for seeding each cloud. Special burners were developed for use with the Anson and DC3 aircraft. These consisted of a long flame tube in which the acetone solution of AgI was injected as a fine spray where it was ignited by a spark from an engine type spark plug. Ram pressure delivered sufficient air to produce a hot flame which was quenched by excess air just before it left the rear of the flame tube. Burners were fitted at the wing tips of the Anson and a few feet below the wing of the DC3 and were supplied with the silver iodide solution under pressure from tanks in the main cabin. The burners were designed primarily for continuous seeding of a large area and consumed 1 to 2 gallons of solution per hour of operation, each gallon containing 500 gm of AgI. The burner was kept on for the complete passage under or through the cloud, and at the aircraft speeds used, about 4 gm of AgI would be distributed per mile. Thus approximately 10 gm of AgI was injected into each cloud. These burners have been tested for effectiveness on the ground, and of the order of 10^{13} nuclei, active at -10° C, are produced for each gram of AgI burnt. The threshold temperature at which any of the smoke particles become active as ice nuclei is about -4 to -6° C. It is known from airborne cold box tests that active nuclei are produced in flight, and that the burner efficiency under these conditions is similar to that on the ground.

3. Results

The results of all the experiments are summarized in Table 1, which lists the most significant data and observations obtained.

The cloud base temperature was measured on a calibrated aircraft thermometer; the temperature at the cloud top was not always measured however, particularly when the seeding was done at the base level. The figure quoted is then estimated from available radiosonde and synoptic information, taking account of the position of any fronts and the degree of coincidence between the radiosonde and measured values of temperature at cloud base or at the highest level reached by the aircraft. This figure is thus sometimes only an estimate, but it is considered unlikely to be in error by more than 2° C, except in the case of very deep clouds seeded at base level, where the error may be 5° C.

The time interval given in column 9 is that between the commencement of seeding and the first appearance of definite precipitation under the cloud base. Intensity of precipitation was estimated both visually by flying the aircraft through the rain and where pos-

sible by radar, and the descriptions given may be taken roughly to imply the following:
Heavy rain 15 mm/hr Moderate rain 5 mm/hr
Light rain 1.5 mm/hr Drizzle 0.2 mm/hr.

It is clear from the summarized information in the table that the degree of confidence of the cause and effect relationship between seeding and precipitation varies from case to case. In the interests of brevity it is proposed to discuss in detail only a few of the cases given and only those in which fairly clear evidence can be produced for the effectiveness of seeding.

Case A, 15 October 1953. Nhill, Victoria.

General synoptic situation: High pressure system centred 100 miles west of Tasmania, giving rise to light easterly stream over most of south-east Australia.

Summary of flight: The aircraft took off from Nhill at 1545 hours, when three isolated cumuli were observed to the south in an otherwise clear sky. These clouds arose as a result of three scrub fires which were burning in the area – an isothermal layer at 3,200 ft apparently prevented the formation of convective clouds elsewhere. Cloud base was at 7,000 ft where the temperature was $+4.5°$ C, and cloud tops at 13,000 ft. The three clouds were almost identical in both size and shape, with base dimensions approximately equal to the cloud depth (6,000 ft). The clouds were dense and compact. One cloud was selected and seeded underneath its base at 1628 hours, prior to which no changes had occurred in any of the three clouds. The seeded cloud was then kept under observation and periodic traverses made underneath its base. At 1650 hours a few droplets appeared on the windscreen during such a traverse; at 1655 hours rain was falling to the ground. The precipitation was light to moderate and occurred in a column which was traversed in 1 minute (i. e. about $1\frac{1}{4}$ miles wide), with a small region of moderate to heavy rain which occupied about one quarter of the entire width of the rain column. The rain ceased about 1705 hours, by which time the seeded cloud had largely dissipated; shortly afterwards only a small and ragged remnant of the original cumulus congestus remained. The control clouds showed no visible change in shape or appearance throughout the period of observation.

Case B, 4 May 1955. Uranquinty, N.S.W.

General weather: Major low pressure system centred 500 miles east of N.S.W. coast; secondary low pressure centred about 100 miles NNE of operational area, with associated trough line extending to the NW; southerly maritime polar air over most of south-east Australia.

Summary of flight: In the vicinity of Wagga an extensive field of cumuli was observed during the morning. An individual cumulus, together with two other slightly larger cumuli for use as control clouds, was selected at 1145 hours. Cloud base was at 4,000 ft where the temperature was at $+6°$ C and the tops were estimated to be at 12,000 ft.

The aircraft entered the selected cloud at 1154 hours at 10,500 ft, the clear air temperature being $-10°$ C. A well marked updraft was encountered for 45 seconds near the middle of the cloud. Silver iodide continued to be released until the aircraft emerged from the cloud at 1156 hours. A steep 90° turn was then executed and the cloud perimeter circled as the aircraft descended slowly. The cloud was approximately circular in cross-section with a diameter of 3 to 5 miles. At 1206 hours a faint rain echo appeared on the radar screen at a range of 1,500 yards. This echo grew rapidly and was seen to extend to the ground at 1211 hours. At 1220 hours the aircraft was below cloud base and a traverse was made through the rain belt. Precipitation was heavy and concentrated in a column which was traversed in 40 seconds. The seeded cloud was still raining when last observed at 1245 hours. During the period of observation no change in appearance or precipitation was observed in the two control clouds. The seeded cloud only changed appearance well after precipitation had reached the ground when the typical anvil head of a cumulo-nimbus cloud appeared.

Case C. 26 July 1955, Hobart, Tasmania

General weather: Low pressure system centred 500 miles to west producing NW winds. A few thin Cu over land and extensive isolated layers of Ac over land and sea. No high cloud apart from a trace of Cs to NW.

Summary of flight: A temperature sounding showed that freezing level was at 6,500 ft and the Ac was based at 10,000 ft, where the temperature was $-8°$ C, and had its tops between 12,000 and 12,500 ft where the temperature was -12.5° C. A sheet of Ac was chosen for seeding which was roughly 80 miles by 50 miles in extent and fairly uniform in appearance except that it was somewhat deeper at its southern limit where the base descended to 9,000 ft. A seeding run was made running from north to south entering cloud at 1145 hours at 12,000 ft but descending to 11,500 ft at 1148 hours to keep wholly within the cloud. At 11.57 hours the aircraft commenced to descend through the cloud while turning on a reciprocal course and breaking through the base at 9,300 ft at 1205 hours. The aircraft descended to 8,000 ft while heading north. Seeding was terminated at 1200 hours.

During the seeding run no sign of snow or ice crystals was observed in the cloud which appeared to consist wholly of supercooled water droplets. From the rate in which ice built up on small exposed surfaces and from general experience it was estimated that the cloud water content was between 0.1 and 0.2 gm/m^3. The aircraft headed north till 1214 hours when it turned back southwards again. No precipitation was visible anywhere till 1217 hours when the first streaks were seen at the southern limit of the seeded track. The aircraft entered this at 1225 hours and it was found to consist of small snow flakes 2 to 3 mm across, the precipitation rate being estimated at between $\frac{1}{4}$ and 1 mm/hour. The aircraft turned back northwards at 1229 hours and precipitation was observed from the northern limit of the seeded track at 1235 hours. Thereafter the aircraft kept flying up and down beneath the seeded track. By 1300 hours the precipitation area had extended over the whole length of the seeded track and had broadened in the east-west direction to cover roughly 3 to 5 miles. However, the precipitation did not reach the surface, mostly evaporating before it had reached 4,000 ft. The aircraft then returned to base, landing at 1340 hours. The cloud was still precipitating and showed no sign of evaporation along the seeded track. There was no precipitation anywhere in the cloud sheet except along this track and no other Ac in the area produced precipitation. It is estimated that the total amount of precipitation released at cloud base in the 2-hour observation period was 1 mm over 100 square miles.

4. Discussion of results

(a) *Effect of cloud top temperature on results of seeding*

In Figure 1 the results are grouped according to cloud top temperature. It can be seen that of the 29 clouds colder than -5° C at their tops 72 per cent precipitated after seeding,

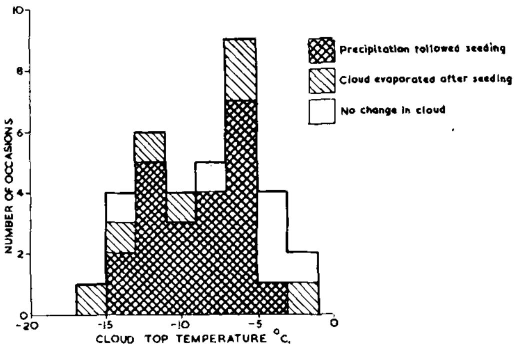

Fig. 1. The effect of cloud top temperature on the results of seeding.

21 per cent evaporated and 7 per cent remained unchanged.

Of the six clouds warmer than -5° C only one cloud precipitated and one evaporated; the other four, or 67 per cent, showed no change.

(b) *Time to release precipitation*

The results are grouped in 5-minute time intervals in Figure 2. Most clouds are seen to precipitate between 20 and 25 minutes after seeding. There is slight evidence that layer clouds tend to take somewhat longer to release precipitation after seeding than do cumuliform clouds. The cases where the time interval was markedly shorter than 20 minutes

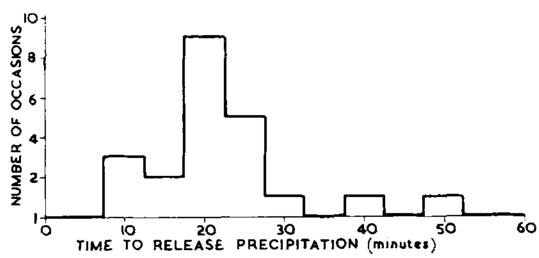

Fig. 2. The time interval between seeding and the release of precipitation.

may be real but it is suspected that in some at least of these cases the rain was due to natural causes. There is also some evidence that when clouds are seeded at the base, the time taken to release precipitation is longer than when they are seeded at higher levels where the AgI smoke particles can act as ice crystal nuclei immediately, but as shown in Figure 3, there is little sign that the depth of the cloud has much effect on the time interval between seeding and the release of rain. When layer clouds are excluded it would seem that deeper clouds seeded at their bases take longer to rain than do shallower clouds seeded in the same way, but the correlation is not very great. Presumably the more violent updrafts in the deeper clouds compensate for their greater depth.

(c) *Quantity of silver iodide required for seeding*

No experiments have been made with very small quantities of silver iodide. Indeed in many cases the number of effective nuclei that have been distributed must have been many tens or hundreds of times the number of raindrops that eventually precipitated. This certainly occurred in case C reported above.

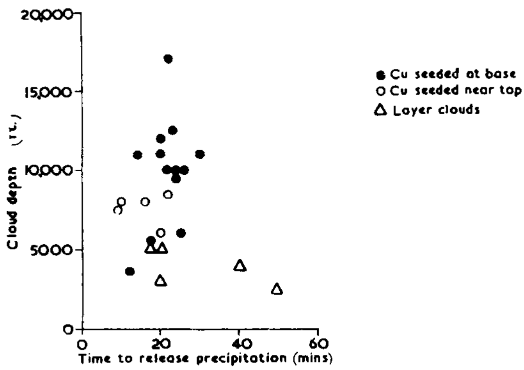

Fig. 3. The effect of cloud depth on the time to release precipitation.

Even in this case, where the initial concentration of smoke particles must have been very high, there was however no evidence of overseeding, or of the clearing of a lane in the cloud. It would seem from this and other similar experiments that such clearing is difficult to achieve with silver iodide seeding, at least with the moderate quantities used in these experiments.

5. Conclusions

From the experiments reported it seems clear that silver iodide is an effective agent for inducing precipitation in supercooled clouds whose temperatures are less than $-5°$ C. The time taken to release precipitation is usually some 20 to 25 minutes after seeding in the case of a cumulus cloud, but may be longer in the case of layer clouds. The question as to whether the precipitation will reach the ground, clearly depends on the quantity released, the height of cloud base above the terrain and the dryness of the air between. In most cases however any reasonably deep cloud that was seeded produced rain that reached the ground. It is of interest to note that these conclusions are very similar to those of SQUIRES and SMITH (1949) in relation to the effect of seeding supercooled clouds with dry ice.

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REFERENCE

SQUIRES, P., and SMITH, E. J., 1949: *Aust. J. Sci. Res.*, A2, pp. 232—245.

Table 1. Summary of results of seeding experiments.

Date	Cloud					Seeding level	Results	Time interval from seeding to precipitation at base	Remarks
	Type	Base		Top					
		Height	Temp.	Height	Temp.				
15.10.53	Cu	7000	+4.5	13000	—8	At base	Mod. rain to ground	25	Only 3 clouds in area over fires. Unseeded clouds unchanged throughout experiment.
20.10.53	Cu	3000	+4	7000	—2.5	At base	Nil	—	Minimum temp. in cloud —4°C. A few drizzle drops at base soon after seeding.
20.10.53	Cu	3000	+4	7000	—2.5	At base	Dissipated	—	Dissipated rapidly 20 min. after seeding.
23.10.53	Cu	3500	+2.5	7000	—4	At base	Mod. rain to ground	12	Two clouds seeded. Unseeded clouds in area also rained.
16.2.54	Cu	3000	+20	15000	—5	At base	Heavy rain to ground	20	Rain heaviest 25 min. after seeding. Ceased 10 min. later. Control clouds did not rain.
15.3.55	Cu	6500	+5	15000	—7	10000	Very light rain to ground	22	Faint radar echo. Large drizzle drops.
4.5.55	Cu	4000	+6	12000	—12	10500	Heavy rain to ground	16	Radar echo in cloud in 12 min. Heavy rain to ground 26 min. Control clouds did not rain.
18.5.55	Cu	6500	—2	10000	—11	9400	Dissipated	—	Dissipated almost immediately. Min. temp. in cloud —5°C.
19.5.55	Layer St Cu	4500	0	8500	—6	8500	Drizzle	40	Slight drizzle, not to ground.
16.6.55	Layer ACu	8000	+2	13000	—7	12500	Light to mod. rain	20	Mostly light rain. Unknown whether it reached ground.
23.6.55	Cu	3500	+3	9500	—9	8600	Light rain	20	Light rain inside cloud 13 min. after seeding, at base 7 min. later. Did not reach ground.
23.6.55	Cu	3500	+3	9500	—9	8000	Dissipated	—	Commenced to dissipate 17 min. after seeding. Nearly gone 6 min. later.
28.6.55	Cu	4000	+1	12000	—14	10000	Light rain	10	Faint radar echo at 9000 ft 7 min. after seeding. Visible rain at base 3 min. later.
16.7.55	Layer St Cu	4300	0	6200	—4.5	5500	Nil	—	No change 30 min. after seeding.
26.7.55	Layer ACu	10000	—8	12500	—12	12000	Light rain	20—50	Rained only in line of seeding. Delay 20 min. at deepest end, 50 min. at other. Not to ground.

Height is given in feet, temperature in °C and time intervals in minutes.

3.8.55	Cu	5000	0	12000	−13	At base	Dissipated	—	Dissipated rapidly 18 min. after seeding.
4.8.55	Cu	3500	+5	9000	−8	At base	Nil	—	No change in 35 min.
8.9.55	Layer St Cu	5000	+2	10000	−6	At base	Mod. to heavy rain	19	Rain accompanied by lowering of base.
16.9.55	Layer ACu	10200	−3	10700	−4.5	10500	Nil	—	No change in 35 min.
16.9.55	Cu	7000	+5	14500	−6	12500	Heavy rain to ground	9	Trace of radar echo soon after seeding. Other clouds in area also rained heavily.
20.10.55	Cu	5000	+13	14000	−6	At base	Mod. rain to ground	24	Base lowering 13 min. after seeding. Rain widespread below cloud 12 min. later.
9.11.55	Cu	9000	+9.5	20000	−11	At base	Very heavy rain to ground	14	Faint radar echo 11 min. after seeding.
11.11.55	Cu	5000	0	15000	−11	At base	Light rain to ground	26	
15.11.55	Cu	8000	+12	18000	−6	At base	Very heavy rain to ground	24	Control cloud though bigger rained 10 min, later and not as heavily as seeded cloud.
23.11.55	Cu	6500	+12	20000	−14	At base	Nil	—	No change observed in 50 min.
11.1.56	Cu	5000	+12	16000	−10	At base	Mod. rain to ground	30	
19.1.56	Cu	7500	+9	20000	−14	At base	Light rain to ground	23	Moderate rain developed 28 min. after seeding and lasted 7 min.
15.2.56	Cu	5500	+12	20000	−16	At base	Dissipated	—	Base lowered 18 min. after seeding. Cloud dissipated 30 min. after seeding.
16.2.56	Cu	6000	+8	17000	−12	At base	Heavy rain to ground	20	Light rain 20 min. after seeding, became heavy 15 min. later.
19.2.56	Cu	6000	+11	12000	−2	At base	Nil	—	Cloud base lowered but otherwise no change.
25.2.56	Cu	7000	+12	17000	−9	At base	Heavy rain	22	Light rain 22 min. after seeding. Heavy 8 min. later. Still raining 45 min. after seeding.
7.3.56	Cu	3000	+19	20000	−10	At base	Mod. rain to ground	22	
18.4.56	Cu	3800	+4	9000	−6	At base	Dissipated	—	Commenced to dissipate slowly 27 min. after seeding. Control clouds did not change.
18.4.56	Cu	5000	+2	9000	−6	At base	Dissipated	—	Started to dissipate 5 min. after seeding.
21.4.56	Cu	2700	+3	8000	−7	At base	Drizzle	18	Only drizzle fell from seeded cloud. Control clouds remained unchanged.

Height is given in feet, temperature in °C and time intervals in minutes.