A Cloud-Seeding Experiment in South Australia

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ABSTRACT

A cloud-seeding experiment was conducted in South Australia from 1957 to 1959 inclusive in which clouds over one of two areas were seeded with silver-iodide smoke released from an aircraft, with random choice of area. No precipitation increases due to seeding were detected.

1. Introduction

A series of experiments is being conducted in Australia to determine the amount by which seeding clouds with silver iodide smoke released from an aircraft can increase precipitation over representative areas. A report has recently been published (Smith, Adderley and Walsh, 1963) of the first experiment, in the Snowy Mountains region of South Eastern Australia. It was considered probable that cloud seeding had caused an increase in precipitation, but the significance level was marginal.

The present report describes the second of these experiments, which took place in South Australia during the winter months of 1957, 1958 and 1959.

2. Design of experiment

Two areas were chosen, each of about 1000 square miles (as shown in Fig. 1). The areas are aligned across the prevailing cloud-bearing wind which is from the west. During the whole of one 'period' of about 12 days, clouds over one area were seeded with silver iodide smoke released from an aircraft, the choice of which area was seeded in a given period being based on a set of random numbers (Fisher and Yates, 1948). The rainfall in both areas was measured for the period. The experiment was designed to determine whether there was a difference in the relationships between the north and south area rainfalls during north-seeded and south-seeded periods, from which inferences might be drawn as to the results of seeding.

3. Measurement of rainfall

Rainfall was measured by the Bureau of Meteorology, using 27 gauges in the north area and 28 in the south. In addition 8 gauges just outside each area were used. Their positions are shown in Fig. 1. All were standard 8-inch rain gauges read at 0900 hours local time each day. The total rainfall recorded by each gauge during a period formed the basis of measurement on which isohyetal maps were drawn, for each period, by using an objective process of linear interpolation between gauges. These isohyets were integrated to provide period rainfall totals for each area.

4. Length of period

The cloud seeding period had an arbitrary minimum length of 10 days. When a period had lasted for the minimum 10 days it was changed to the next period at 0900 hours local time on the first day when, during the passage of a high pressure system, the Weather Bureau forecast no rain in either area.

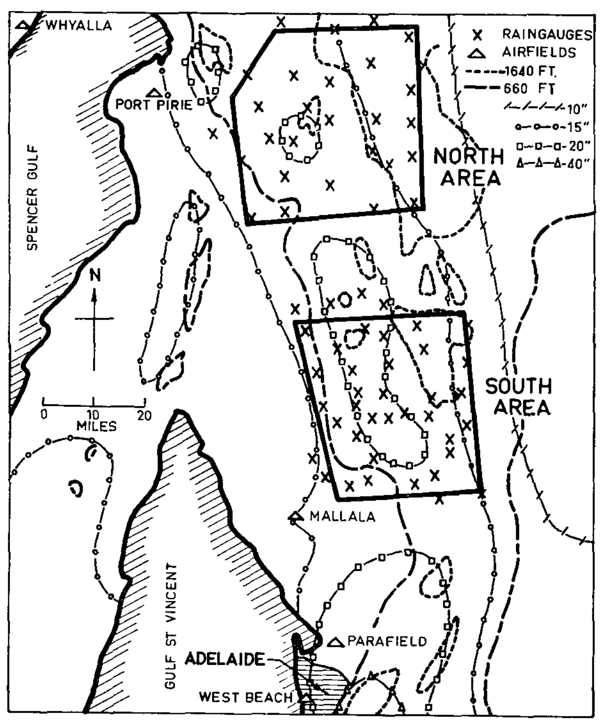

Fig. 1. The experimental areas.

5. Suspension during heavy rain

Arrangements were made to suspend the experiment in periods of excessive rain. The South Australian Department of Agriculture appointed a referee, who knew the experimental areas and their agricultural requirements but did not know which area was seeded at any time. The referee continually assessed the rainfall requirements of the areas as a whole, and if in his opinion further rain would have been detrimental to the interests of the inhabitants he would have suspended the experiment until in his opinion further rain would be acceptable. In fact this provision was not required during the course of this experiment.

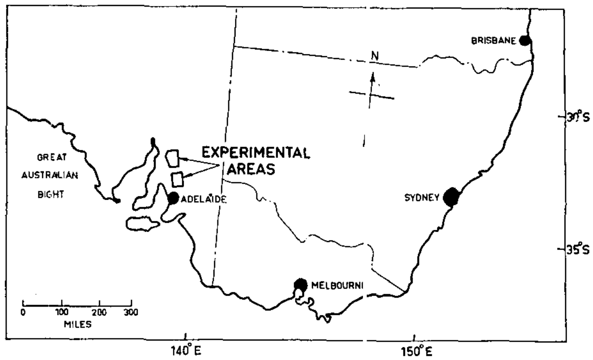

FIG. 2. The areas in relation to Southeast Australia.

6. Area of operations

The operating areas are illustrated in Fig. 1 and their position in Australia is indicated in Fig. 2. Both are similar in respect to climate, topography and orography. They are on the westward side of a range of hills, and consist of flat, low lying land in the west rising to rolling, hilly country in the east with maximum elevation 2500 ft. To the east of the areas the land falls steeply to a plain at about 1000 ft elevation. Most of both areas are fairly densely settled, the principal products being wheat and sheep.

7. Climate

The experiment took place in an area with an annual rainfall of about 20 inches (isohyets are shown in Fig. 1). Most of the rain falls during the winter when it is fairly regular and gentle, with no snow. In summer, rain falls mostly in the form of rare, destructive thunderstorms. The experiment was therefore planned to take place in the winter, when suitable clouds were expected to be of relatively frequent occurrence and rainfall increases would be welcome in most years. During the winter months (May to October, inclusive) typical weather patterns show two to three inches of rain falling on about 11 days per month, with the frequency varying little between the plains at the western edge of the areas and the hills, while the intensity is greatest somewhat to the west of the crests of the hills.

High pressure systems pass from west to east with a period of about six days. In the winter months most of them pass to the north of the experimental areas, bringing fine weather. Low pressure systems also pass from west to east, usually to the south of the experimental areas, their longitudes being between those of the highs.

The incidence of clouds and rainfall in this area in winter is usually associated with the passage of these lows, and meteorological information led to the expectation that the following sequence of events would be typical of a well-developed system. Prefrontal altostratus moving in from the northwest is replaced on the passage of a cold front by large cumulus degenerating to smaller cumulus, both coming from the west. A secondary cold front with some cumulus follows and the wind moves to southwesterly, the weather clearing as the next high pressure system approaches.

It seemed likely that many of the cumuli and probably some of the altostratus would meet the requirements for seeding with silver iodide (see Section 10 below).

8. Aircraft

The aircraft used were an Avro Anson and a Douglas DC-3 in 1957 and a Cessna 310B in 1958 and 1959. The Anson had no oxygen and could not fly in clouds or in darkness, the other two aircraft were fully equipped for blind flying and had oxygen and de-icers. All had full radio and radio navigation aids.

9. Cloud-seeding equipment

Silver iodide smoke was generated by burners under the aircraft's wings. The equipment used in 1957 and 1958 and its performance have been described by Smith *et al.* (1958). In 1959, equipment of a slightly different type was used, the burners being fed by gravity and the solution atomized by a vortex and a spinning disc. The freezing nucleus output of the new burners was tested in the same way as the original type and was found to be the same within the limits of measurement.

10. Operational procedure

The intention was to seed as high a proportion as possible of suitable clouds which passed over the target area. Clouds were regarded as suitable if their tops were colder than −5C, their depth exceeded half the terrain clearance of their bases, and they were dense and compact, with life exceeding 30 min; in case of doubt as to the suitability of the clouds they were seeded, even if raining already. The specification was most often met by cumulus or altostratus.

Clouds were seeded in a seeding area displaced upwind from the target area to allow for the time interval between seeding and the arrival of rain on the ground, assuming an interval of 30 min for turbulent clouds and

45 min for non-turbulent layer clouds, with an additional 1 min for cumulus and $1\frac{1}{2}$ minutes for stratiform clouds per thousand feet terrain clearance of the bases. With cumulus clouds the aircraft normally flew at the cloud base while with stratiform clouds the seeding was usually at the −5C level unless the aircraft was forced to descend by icing.

A more comprehensive description of the procedure in a similar experiment has been given by Smith *et al.* (1963).

11. Weather conditions encountered

Rainfall during the winters of 1957 and 1959 was below normal while that of 1958 was about normal. These three years, therefore, probably provide a good sample of the type of weather in this region during which rainfall increases would have been desirable.

Clouds suitable for seeding occurred much less frequently than was expected. In general the weather patterns observed were substantially of the type described above (Section 7) but they frequently passed to the south of the experimental areas, particularly in 1957 and 1959.

Seeded days were divided into three categories, cumulus, stratiform and indeterminate, according to the predominent type of cloud encountered. Some statistics relevant to the three categories are given in Table 1.

Deep cumulus clouds with tops colder than −10C (which are regarded as the most suitable type for seeding) were encountered on only seven days during the entire experiment. This was far below expectations.

Stratocumulus clouds were frequently observed to give rain but their tops were usually limited by inversions to around the freezing level, and they were thus unlikely to have been affected by the seeding.

Deep stratiform clouds with tops extending to substantially sub-freezing levels were encountered relatively frequently, but gave no visual indication at any time that they were affected by seeding. These clouds were generally associated with westerly or west-north-westerly winds of 30–40 knots.

As a result of the observations made during this experiment, the authors believe that in this area the clouds, which usually formed in Maritime air streams, rained predominantly by the coalescence process and were generally not suitable for stimulation by silver iodide.

12. Rainfall and seeding figures

The mean precipitation in inches for each area during each period is given in Tables 2 and 3, for the north-seeded and south-seeded periods, respectively, together with the beginning and end dates and the duration of seeding.

13. Rainfall totals

Table 4 gives the total rainfalls in inches during the three-year experiment for north-seeded and south-seeded periods.

The total rainfall in the north area was slightly less than that in the south area, both in north-seeded and in south-seeded periods. The ratio of the rainfall in the north area to that in the south area was slightly less

TABLE 1. Characteristics of clouds on seeded days.*

	Cumulus	Stratiform	Indeterminate
Top temp (deg C)			
Median	$-7\frac{1}{2}$	−12	−7
Quartiles	−6 −12	−6 −15	−4 −10
Top height (1000's of ft)			
Median	10.5	14	10
Quartiles	9 13	13 17	8 13
Base temp (deg C)			
Median	+5	+1	+7
Quartiles	+4 +6	−1 +5	+3 +8
Base height (1000's of ft)			
Median	3	9	3
Quartiles	2.5 3.5	6 10	2.5 5.5
Number of seeded days	22	41	45
Number of hours seeding	73	109	125

* *Note.* The height of the tops of clouds is sometimes given as greater than a certain height, e.g., when the aircraft climbed in stratiform clouds without reaching the top. In these cases the cloud top has been assumed to be 2000 ft higher and 5C colder than the given value. This will lead to estimates which are thought to be reasonable except in the case of stratiform clouds, the height of the tops of which may be underestimated.

TABLE 2. North-seeded precipitation.‡

Period No.	Duration	Mean precipitation North area	Mean precipitation South area	Seeding hr: min
	1957			
2	6 May–23 May	0.218	0.600	1:55
4	14 June–25 June	1.848	1.905	6:24
7	23 July – 2 Aug.	0.523	0.541	0
8	3 Aug.–13 Aug.	0.817	0.758	7:15
10	27 Aug.– 7 Sept.	0.552	0.512	12:40
14	15 Oct. –26 Oct.	1.165	1.003	15:59
	1958			
16	23 April– 6 May	0.240	0.264	0
19	1 June–10 June	0.091	0.284	3:45
20	14 June–26 June	0.017	0.044	13:00
23	27 July –10 Aug.	0.841	1.188	4:30
26	10 Sept.–22 Sept.	2.193	2.825	9:35
28	12 Oct. –23 Oct.	0.800	0.933	8:30
	1959			
31	12 June–28 June	0.209	0.178	0
33	9 July –20 July	0.167	0.149	4:00
35	31 July –16 Aug.	0.969	1.588	2:55
36	17 Aug.–26 Aug.	0.020	0.020	0
38	8 Sept.–25 Sept.	1.008	0.896	13:45
39	26 Sept.–13 Oct.	0.926	0.974	7:20

‡ See note following Table 3.

TABLE 3. South-seeded precipitation.‡

Period No.	Duration	Mean precipitation North area	Mean precipitation South area	Seeding hr:min
	1957			
1	26 April– 5 May	0.494	0.623	4:33
3	24 May–13 June	0.031	0.033	3:40
5	26 June–10 July	1.141	0.824	0:19
6	11 July –22 July	0.955	1.112	7:00
9	14 Aug.–26 Aug.	0.753	0.340	5:12
11	8 Sept.–18 Sept.	0.225	0.663	13:00
12	19 Sept.– 1 Oct.	0.354	0.231	16:15
13	2 Oct. –14 Oct.	0.111	0.153	6:49
	1958			
15	13 April–22 April	0.726	0.726	1:20
17	7 May–20 May	0.783	1.578	17:55
18	21 May–30 May	0.840	1.503	11:35
21	27 June– 8 July	0.022	0.314	15:30
22	9 July –22 July	1.400	1.079	22:10
24	11 Aug.–28 Aug.	2.545	2.339	14:25
25	29 Aug.– 9 Sept.	0.837	0.893	5:15
27	29 Sept.–11 Oct.	1.518	1.537	25:40
29	24 Oct. – 3 Nov.	0.219	0.068	9:45
	1959			
30	1 June–11 June	0.336	0.277	4:25
32	29 June– 8 July	0.007	0.007	0
34	21 July –30 July	1.667	1.162	7:35
37	27 Aug.– 7 Sept.	0.017	0.039	0
40	14 Oct. –25 Oct.	0.274	0.587	2:45

‡ *Notes on Tables 2 and 3.* There were gaps of a few days between Periods 19 and 20, 22 and 23 and 26 and 27. These were due to the maintenance requirements of the aircraft, periods 20, 23 and 26 starting, like the other periods, on days of forecast fine weather.

In subsequent analysis and discussion, the period precipitations in the north area and south area, respectively, are denoted by N and S.

The starting date of the seasons operations varied from year to year. This was due to the availability of aircraft.

During Period 25 the pilot was sick for seven days so no flights took place. There is a case for omitting this period from the analysis: however it does not affect the conclusions, and it has been included.

in north-seeded periods than in south-seeded periods, whereas the reverse would be expected if seeding caused an increase in rainfall. A statistical analysis of the rainfall figures is undertaken in the following paragraph.

14. Statistical analysis

Two statistical tests were carried out on the period precipitations. The values of the ratio of the precipitation in the north area to that in the south area, N/S, were arranged in order of magnitude, and a Wilcoxon (Mann and Whitney, 1947) test applied to the array divided into north-seeded and south-seeded ratios gave a two-sided significance level of 0.5.

A regression analysis was performed using a square-root normalizing transformation. A t-test applied to the difference of the means of departures from the regression line gave a two-sided significance level of 0.6.

TABLE 4. Rainfall totals.

			Inches
North-seeded	North area	N_n	12.604
	South area	S_n	14.662
South-seeded	North area	N_s	15.255
	South area	S_s	16.088
		N_n/S_n	0.87
		N_s/S_s	0.96

If the north-seeded and south-seeded periods were random samples from the same population it would be expected that the variance of their departures from the regression line would be the same. In fact the variance in north-seeded periods was less than that in south-seeded periods. An F test applied to the variance ratio gave a significance level of 0.02.

15. Discussion of results

Both methods of analysis described in Section 14 gave the same result, that the difference between the precipitation balance in north-seeded and south-seeded periods might well have arisen by chance if seeding had no effect. There is, therefore, no evidence that cloud seeding influenced the mean precipitation.

The authors do not know of any physical process by which cloud seeding could have caused the difference in variance between the north-seeded and south-seeded precipitations, and to continue the experiment in order to investigate this effect would not be justified on economic grounds.

The cause of the lack of demonstrable effects appears to have been the infrequent occurrence of clouds suitable for seeding and the predominance, in the maritime situations encountered, of rain formation by the coalescence process.

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