Cloud Seeding Effects on Different Daily Rainfall Amounts

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ABSTRACT

The results of the cloud seeding experiment in New England, Australia, have been stratified to show different effects of seeding on different daily rainfall totals. No effect was detected on days with an area average rainfall of less than 0.1 inch, which contributed about 21% to the total rainfall. Days with between 0.1 and 0.5 inch, contributing 45% to the total rain, showed increases of 10–20%. The 0.5–1.0 inch class, contributing about 22%, showed an apparent 10% decrease. There were too few cases to give a meaningful result for heavier falls.

1. Introduction

The results of the cloud-seeding experiment in New England, Australia, described by Smith *et al.* (1965), have been re-analyzed in an attempt to discover any differences in the effects of seeding on different daily totals of rainfall. It was hoped that this might reveal reasons for the variability of the gross results of the original experiment, and make any future operational or experimental seeding in the area more efficient. Insofar as any results apply to other areas, it was hoped that they would suggest more sensitive statistical tests of seeding effectiveness, and perhaps shed light on the physics of the seeding process.

In a preliminary study, the shape of the daily rainfall frequency distribution during seeding was compared with that in the period before seeding began. This suggested that seeding might have increased low and moderate rainfalls and perhaps decreased high rainfalls. However, the vagaries of historical rainfall records and the flimsiness of the link with seeding made certainty impossible. This result stimulated the study described here, in which the original experimental results were stratified in detail by daily rainfall amount.

TABLE 1. Results for all rainfall in the New England experiment.

Year	Root double ratio
1958	1.32
1959	1.02
1960	1.07
1961	0.88
1962	1.21
1963	0.86
Six years	1.04

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2. Summary of the New England experiment

The experiment has been described by Smith *et al.* (1965), and in greater detail, with daily reports, by Smith *et al.* (1963a–e, 1964). Seeding with silver iodide from aircraft began in 1958 and continued for six years in two similar areas (denoted north and south) on the western slopes of the Great Dividing Range in New South Wales. The experiment was divided into periods whose exact length depended on meteorological conditions but which averaged about a fortnight. During each period one of these areas, selected on a random basis, was seeded and the other used as a control. The effects of seeding were measured by the double ratio, defined as the ratio of N-area average rainfall to S-area rainfall in N-seeded periods, divided by the same ratio in S-seeded periods. (Our results will be shown as the square root of this double ratio, because this shows directly the proportionate change in rainfall in seeded areas.) The overall results of the experiment are shown in Table 1. It can be seen that there was considerable variation from year to year, but the result for the six years as a whole was a marginally significant 4% increase in rainfall (Smith *et al.*, 1965).

3. Stratification of daily rainfall

To investigate different effects of seeding in different rainfall intensities, the days on which either of the areas had an area average of at least 0.01 inch of rain were divided among seven classes according to the day's rainfall and a root double ratio calculated for each class. The classes used were 0–0.10 inch, 0.11–0.20, 0.21–0.30, 0.31–0.40, 0.41–0.50, 0.51–1.00, and over 1 inch. The procedure was first to allocate days according to the N-area rainfall, and to calculate a root double ratio for each class, and then to repeat the process using the S-area rainfall. This gave two double ratios for each class. They were usually, but not always, similar.

TABLE 2. Root double ratios stratified by daily rainfall. The numbers of days in each class (the average of north and south stratifications) are in parentheses. Rainfall amounts are in inches.

Rainfall	1958–59	1960–61	1962–63	Six years	Percentage of total rain in each class
0–0.10	0.96 (248½)	0.97 (302½)	1.01 (223)	0.98 (774)	21.3
0.11–0.20	1.46 (32)	1.00 (32)	0.94 (24½)	1.11 (88½)	12.1
0.21–0.30	1.30 (21½)	1.38 (17½)	1.13 (18½)	1.09 (57½)	13.0
0.31–0.40	1.13 (12½)	1.17 (17)	1.45 (13)	1.10 (42½)	11.8
0.41–0.50	1.62 (4½)	1.44 (9)	0.95 (8)	1.17 (21½)	7.7
0.51–1.00	0.92 (15½)	0.97 (13)	0.93 (16)	0.89 (44½)	21.9
>1.00	1.31 (4½)	0.97 (4)	1.26 (6)	1.01 (14½)	12.2

After consideration of various methods of combining them, a simple mean was used.

The daily figures used were the averages for each area calculated by the Australian Commonwealth Bureau of Meteorology. The number of days and proportion of rainfall in each class for the six years of the experiment are shown in the last two columns of Table 2. It should be noted that the spectra for the areas as a whole differ systematically from spectra for individual stations in the areas. Localized heavy falls are averaged over a relatively large area, so that the number of exceptionally high (>1 inch) area figures is much less than the number at individual stations, and the average rainfall per rain day over the areas is less than 0.15 inch, compared with over 0.3 inch at most local stations.

4. Results and discussion

Fig. 1 and Table 2 show the values of root double ratio for the six years, and for the two-year periods 1958–59, 1960–61 and 1962–63. Because of the scatter in the highest class, which is probably due to the small number of days, the values for this class in this and subsequent cases are not plotted, although they are stated. The number of days shown is the average of the number according to the stratification by N-area rainfall and the number by S-area rainfall. It can be seen that the results consistently indicate a value close to unity for the lowest class, relatively high values for classes up to 0.5 inch, and values consistently less than one for the 0.51–1.0 inch class. The values for the highest class were generally above one, but very variable. The results therefore suggest that over the six years seeding caused an increase in rainfall of 10–20% on days giving between 0.1 and 0.5 inch, with a possible decrease in rainfall in the 0.5–1.0 inch class. Because of the smaller number of days concerned, this decrease is not as well attested as the increases, although the results are consistent throughout the experiment. The root double ratio for all days with more than 0.5 inch is 0.93 (59 days). As mentioned above, these rainfall figures must probably be doubled at least if they are to be related to values recorded at individual stations.

Although values for individual years show considerable variation, it is interesting to compare the years

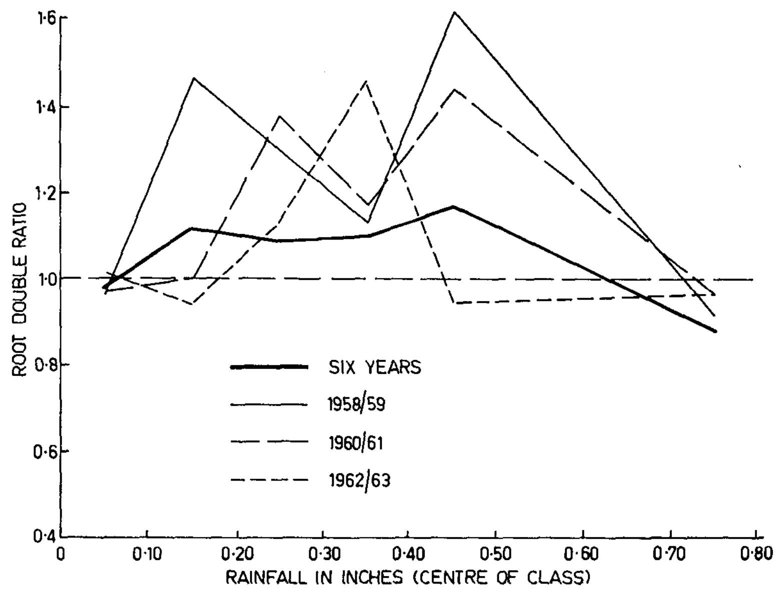

FIG. 1. Results of stratification for all days.

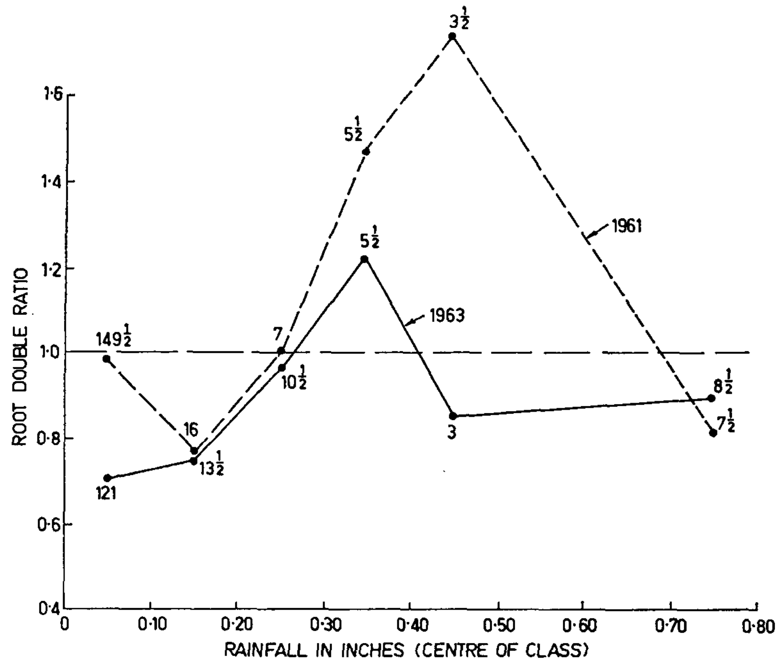

FIG. 2. Stratification for the years with overall root double ratios <1. Ratios for falls >1 inch are: 1961, 1.00 (2 days); 1963, 1.03 (3 days). The number of days contributing to each point is shown.

having exceptionally bad and exceptionally good overall results with the general pattern. Fig. 2 shows the plots for the years with overall root double ratios <1. Both show maxima in the 0.3–0.5 inch range, consistent with the general pattern. The exceptionally good years, however, shown in Fig. 3, show high values in the lowest class, unlike the general pattern. The year 1958 has exceptionally high values for the lowest three classes, but only average values for the others. This suggests that if Bowen (1966) is right, and 1958 differs from succeeding years because of persistence, then persistence is most effective for low rainfall. However, as already stated, results for single years display considerable and apparently random spread.

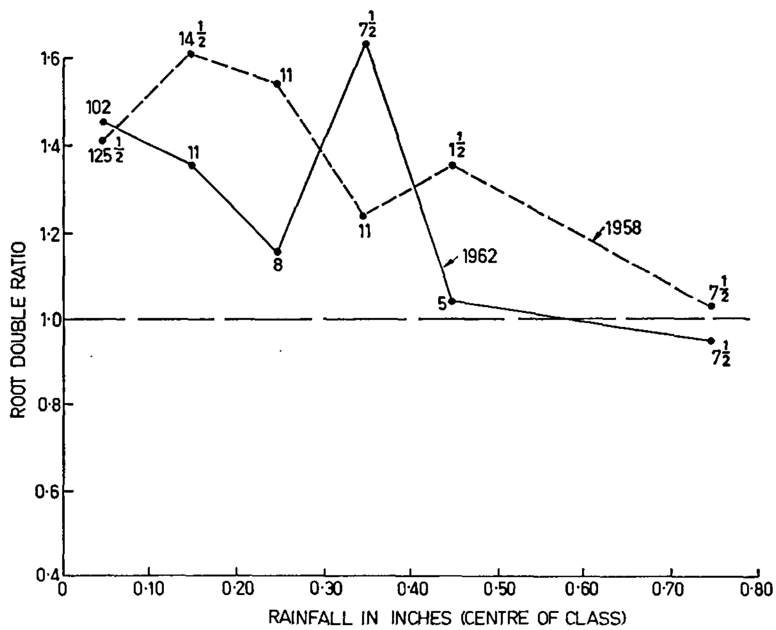

FIG. 3. Stratification for the two years with highest overall root double ratios. Ratios for falls >1 inch are: 1958, 1.67 (1½ days); 1962, 1.23 (3 days).

Significance levels are not stated for the results. Because the stratification was planned after the readings had been inspected, confidence limits would be of very doubtful validity, as well as being difficult to calculate for the variables involved. The conclusions would be better used to plan future experiments to which statistical tests could be applied with assurance.

5. Conclusions

The results as measured by the root double ratio strongly suggest that cloud seeding consistently increased rainfall on days with area averages between 0.1 and 0.5 inch. The increase in these classes averaged about 10–20%, but unfortunately these classes contributed only about 45% to the overall total rain. The 0.51–1.0 inch class, contributing about 22% to the total, apparently showed a decrease of about 10%. No overall effect was found for rainfall on days with less than 0.1 inch (contributing 21% to the total), and because there were insufficient data, conclusions could not be drawn for days with more than 1 inch (contributing 12%). The results suggest that a redistribution of heavier falls contributes to, but does not account for, the increase in moderate falls.

In general, the results support other indications that cloud seeding is more effective in increasing moderate rainfall than in affecting light or heavy areal averages.

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