Cloud Seeding and Cloud-to-Ground Lightning[1]

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ABSTRACT

During the summers of 1958 to 1962, convective clouds over a mountain range in southeastern Arizona were seeded by means of airborne silver-iodide generators. The data collected do not allow a conclusion that the seeding influenced the amount of cloud-to-ground lightning.

1. Introduction

A number of theories on thunderstorm electrification specify that supercooled water drops play an important role in the charging process [see, for example, Mason (1957)]. For this reason, it has been considered possible, that if the quantity of supercooled water in a building convective cloud could be reduced substantially by ice-nuclei seeding, this might lead to a change in the charging rate and the amount of lightning.

Although there is some physical plausibility in this reasoning, few systematic experiments to test the effects of ice nuclei on the electrical properties of clouds have been performed. Imyanitov and Chuvayev (1955, 1956) reported the results of seeding individual convective clouds with dry ice. They indicated that ice-nuclei seeding was followed by an increase in the electric field strength. In a mimeographed report to the Atomic Energy Commission dated 15 July 1959, P. B. MacCready, Jr., K. M. Beesmer and T. J. Lockhart reported similar results following the seeding of convective clouds in northern Arizona.

During the period 1957 to 1959, the California Division of Forestry working with the U. S. Forest Service carried out cloud seeding operations to test if the number of lightning-caused forest fires could be reduced (Robinson, 1960). It was concluded that seeding from the ground with silver-iodide generators "did not significantly increase or decrease the incidence of lightning fires."

For a number of years the U. S. Forest Service has had a vigorous program of research in Montana concerned with the physics of lightning and lightning suppression. The latest reports on this research were given by Baughman and Fuquay (1965) at the National Meeting of the American Meteorological Society held in Denver on 26 January 1966. They stated, "Less lightning was recorded on treated than on untreated storm days," but the abstract does not specify numbers of lightning strokes or results of statistical tests.

In summarizing the status of cloud seeding, the Panel on Weather Modification of the National Academy of Sciences (1966) reached the conclusion that "Experiments in lightning suppression are beginning to show promising results according to reports from the only active project expressly undertaken for this purpose (Project Skyfire, U. S. Forest Service)." In support of this conclusion, the Panel cited a 1962 report by Fuquay and Baughman summarizing two years of seeding trials. The Academy report notes that, "The investigators emphasize: (1) that the results were not statistically significant in their opinion, the significance level being 0.12. . . ."

Starting in 1957, two series of randomized tests involving the seeding of convective clouds by means of airborne silver-iodide generators were performed in southeastern Arizona. It should be noted that these experiments were *not* expressly undertaken for the purpose of lightning suppression. The concentrations of ice nuclei active at about −10C were estimated to have been 1 to 10 per liter (Battan, 1966), a quantity which in principle should be of the order expected to be effective in modifying the ice-crystal precipitation process. However, these quantities are far below, perhaps by 1000 times, the amount needed to "overseed" a convective cloud. The term "overseed" is used to indicate a seeding rate which would lead to 1 to 100 ice crystals per cubic centimeter of cloud. In theory, if such a cloud be effectively overseeded and virtually all the supercooled water could be frozen, the electrification process would necessarily be modified if it depended on the presence of substantial quantities of supercooled water.

Though recognizing that the seeding rates in the Arizona experiments were far below the level for overseeding, it still seemed to be in order to observe whether or not a significant change in cloud-to-ground lightning was produced. This article reports the analysis of the

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observations of cloud-to-ground lightning on seeded and not-seeded days.

2. Design of experiment

The design of the experiment has already been described by Battan and Kassander (1960) and Battan (1966). One of a pair of days was seeded on a random basis. An airplane carrying a silver-iodide generator was flown along a track upwind of the Santa Catalina Mountains which had been selected as the target area. This mountain range has an area of about 200 mi². The airplane normally flew back and forth along the same track at the same altitude for periods ranging from 2 to 4 hr between 1230 and 1630 MST.

The frequency of cloud-to-ground lightning between 1300 and 1800 MST was determined visually by observers located in a U. S. Forest Service ranger tower on a centrally located peak (Mt. Bigelow at an elevation of 8500 ft). The occurrences of lightning over the target area were read into a tape recorder and tabulated later by the same observers. In the course of the experiments, various lightning counters were tested, but were found to be unsatisfactory. It is realized that visual counting, over a mountain area in particular, involves a certain amount of subjectivity, particularly in deciding whether or not a lightning stroke hits inside the "target area." Nevertheless, by keeping the observers uninformed of whether or not seeding was taking place, the scheme we employed should have produced unbiased observations of lightning occurrences.

3. Results

Although the seeding tests were started in the summer of 1957, lightning counts were not begun until the following summer. During this period the seeding was done by flying the aircraft at about the −6C level (18,000–20,000 ft).

Table 1 presents a summary of lightning data on those pairs of days on which satisfactory observations were made on both days of the pair. On some days the cloud bases were so low as to obscure visibility from the ranger tower. In such an event both days of the pair were discarded and not used in this analysis.

Although there were 56 per cent more strokes on the seeded days, the results are not statistically significant. The likelihood of obtaining the observed results under the hypothesis that seeding had no effects were calculated by means of the signed-rank test and the Mann-Whitney U test. They yielded one-tailed probabilities of 0.16 and 0.22, respectively. The chief reason for the failure of such a large percentage difference to be statistically significant lies in the great variability of lightning occurrence. This point will be illustrated in Table 3.

TABLE 1. Frequency of cloud-to-ground lightning strokes observed on seeded and not-seeded days during the summers of 1958, 1959, and 1960.

Year	Numbers of pairs of days	Seeded days	Not-seeded days
1958	16	1265	138
1959	15	360	692
1960	14	368	446
Total	45	1993	1276

In 1961 the seeding program was changed in the manner already described by Battan (1966). One of the chief differences from the earlier program was that the prediction criteria were altered in such a way as to reduce the number of experimental days with no rainfall. The second important change was that in the new program the seeding airplane was flown at a level 1000–2000 ft below the cloud base but still upwind of the mountain base target. This program extended over the three summers, 1961, 1962, and 1964, but lightning observations were taken only during the first two years. The chief reasons for the discontinuance after 1962 were that it was found that lightning was correlated with rainfall amounts and it did not appear that the tests were likely to establish either a lightning increase or decrease. Furthermore, there was a shortage of available funds.

TABLE 2. Frequency of cloud-to-ground lightning strokes observed on seeded and not-seeded days during the summers of 1961 and 1962.

Year	Numbers of pairs of days	Seeded days	Not-seeded days
1961	15	937	1628
1962	7	252	278
Totals	22	1189	1906

Table 2 shows a summary of the results of the data collected in 1961 and 1962.

These data show 38 per cent less lightning on the seeded days, but as was the case in the earlier program, the results are not statistically significant. The signed-rank and Mann-Whitney U tests yield one-tailed probabilities of 0.17 and 0.21, respectively. Again the lack of significance in the light of a fairly large percentage difference is ascribable to the large variability in daily occurrence of lightning.

It can be seen in Table 3 that only a few days with very high lightning frequencies account for most of the differences in the totals. Note for example that one day (14 August 1958) with 747 lightning strokes on a seeded day accounts for the difference between the totals in the 1958–1959–1960 experiment.

If all the data in Tables 1 and 2 are combined, the results are 3182 lightning strokes for seeded and not-seeded days. The Mann-Whitney U test yields a one-tail probability of 0.09, but since in this case the most reasonable alternative hypothesis is that seeding either increased or decreased lightning, both tails must be included yielding a probability of 0.18. This value is relatively low because of differences in the distributions

TABLE 3. Frequency distribution of cloud-to-ground lightning over the Santa Catalina Mountains during periods 1300 to 1800 on seeded and not-seeded days.

	Seeded days		Not-seeded days	
	1958, 1959, 1960	1961, 1962	1958, 1959, 1960	1961, 1962
0–20	10	2	6	1
21–40	4	3	2	3
41–60	2	0	2	0
61–80	2	2	1	1
81–100	0	0	1	1
101–200	6	2	4	3
201–300	0	1	1	2
301–400	0	1	0	2
>400	1 (747)	0	0	0
Totals	25	11	17	13

in seeded and not-seeded days even though there is no difference in the total quantities.

4. Summary

Since the estimated ice-nuclei concentration produced in the seeding tests were far below the levels needed for overseeding, the results presented in this article are not surprising. However, the inability to discover either an increase or decrease in lightning frequency is worth reporting as a background for other research on this subject.

In closing, attention should be drawn to an illustration published in an earlier paper (Battan, 1965) showing a correlation between the frequency of cloud-to-ground lightning and mean rainfall, both measured in the period 1300 to 1800 MST over the Santa Catalina Mountains.[2] Since publication of that paper, additional data were accumulated. Calculations yielded a regression line having the form $N=430\ R^{0.76}$. The correlation coefficient was found to a highly significant 0.65 even though there clearly is considerable scatter. This results leads to the speculation that an increase of rainfall from clouds such as the orographic cumulonimbus in southeastern Arizona might be accompanied by an increase of cloud-to-ground lightning.

[2] Note that the proper form of the equation for the line shown in Fig. 5 of Battan (1965) should have been $N=2140\ R^{1.3}$.

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