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SEEDING OF SUMMER CUMULUS CLOUDS

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SEEDING OF SUMMER CUMULUS CLOUDS*

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Abstract

A description is given of a program of randomized seeding of orographic cumuli over southeastern Arizona. This investigation, started in 1957, is still in progress. The aims have been to learn more about natural cloud processes and to ascertain if airborne silver iodide seedings can modify them. It will be shown that analyses of cloud photographs, radar observations, lightning observations and rainfall data suggest that cloud seeding modified the natural cloud processes. However, the changes observed so far have not been large enough to conclude that effects have positively been established.

1. Introduction

As a result of basic studies of the properties of summer cumuli carried out during the period 1953 to 1957 by The University of Arizona and the University of Chicago, it was established that building cumuli in southeastern Arizona are generally supercooled to levels colder than -10° C. Furthermore, it was found that over the mountain ranges surrounding Tucson, Arizona, there are large convective clouds for 40 to 50 days each summer and that most of these clouds do not rain naturally. It was concluded that the prevalence of supercooled cloud droplets indicated a deficiency of effective ice nuclei,

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and that as a result, these clouds might be amenable to modification through the introduction of artificial nuclei.

On the basis of present-day theories of clouds and precipitation, a program of observations was devised from which it was possible to obtain those measurements which would permit a study of natural physical processes and an evaluation of the effects of artificial nuclei.

Field experiments were conducted during the summers of 1957 and 1958. The first year's program consisted of a joint operation by the Universities of Arizona and Chicago. The research was sponsored in part by a National Science Foundation grant to the University of Chicago. The investigations conducted in 1958 have been conducted by The University of Arizona under Grant Number NSF-G5607 with an equal contribution of State funds. This final report summarizes the results of the research conducted through 1958. As will be seen below, the results to date have been very encouraging.

2. Design of Experiment

The design of the seeding experiment has been discussed in some detail by Battan and Kassander (1958a)*. Briefly, the procedure involved an objective prediction, made prior to 0900 MST of each day, as to whether or not cumulus congestus or cumulonimbus clouds would form over the Santa Catalina Mountains. The main criterion for the prediction was whether or not the precipitable water at Tucson, Arizona, exceeded 1.10 inches. When this value was exceeded the day was considered to be suitable for seeding, and an envelope was opened which specified which of two adjacent suitable days would be seeded. If more than one unsuitable day separated two suitable days, the first day of the pair was rejected and a new pair was started. The scheme of randomized

*Drs. K. A. Brownlee and W. Kruskal of the Department of Statistics of the University of Chicago assisted in the design of this experiment.

pairs was adopted in order to take into account day-to-day correlations and to assure that there would be an equal number of seeded and not-seeded days.

The actual seeding was carried out with an Australian-type airborne silver-iodide generator suspended under the wing of a Supercub airplane owned and flown by the Hudgin Air Service. The flight plan involved repeated passes at about the -6° C. level on a track upwind from the mountain range. The pilot normally started the generator at about 1230 MST and continued his flight until all the seeding material was exhausted or the burner went out. Normally the seeding period was of the order of 4 hours. The generator consumed a 20 per cent solution of silver iodide in acetone at a rate of 2 to 2-1/2 gallons per hour.

3. Observations

In order to permit studies of cloud and precipitation processes a variety of observations were made.

Properties of visual clouds. -- A pair of carefully calibrated ground-located K-17 aerial cameras was installed at the ends of a 3-mile base leg. Both cameras were triggered simultaneously at 10-minute intervals. When particularly interesting clouds were present photographs were taken at 1-minute intervals. From the pairs of photographs (see Fig. 1) it was possible to make accurate calculations of cloud top heights. (See Kassander and Sims, 1957.)

Time lapse photographs at 7-second intervals were also taken with a 16-mm. camera.

Precipitation formation as revealed by radar. -- An AN/TPS-10A radar set was operated throughout the summer. This set was modified to give a symmetrical one-degree beam. The scanning rate was rigidly controlled so that the vertical scanning rate was exactly one per second and the azimuthally

Figure 1

scanning rate was exactly one degree per second. The region over the mountain range was examined once every 3 minutes.

From the film records of the radar scope, it is possible to study the location of the initial precipitation echoes, the rates of spread of precipitation, and the frequency of large convective clouds.

Rainfall. -- A network of 29 recording rain gauges was installed to measure the amount and distribution of rainfall.

Lightning. -- A lightning counter of commercial design and a Weather Bureau electric field meter were installed on Mount Bigelow, a peak which has an elevation of about 8,500 feet. Various difficulties prevented consistent lightning observation with these two instruments; however, two observers made reliable visual observations of cloud-to-ground lightning strokes.

4. Results

During both 1957 and 1958, 16 pairs of days were investigated. Although the analysis is still in progress, the results to date suggest that the AgI seeding caused some important changes in the natural cloud processes. The results obtained thus far are briefly summarized in the following paragraphs.

Rainfall. -- When data from both years were combined it was found that the mean rainfall per gage was 30 per cent higher on the seeded days; however, the probability that the observed differences in the mean rainfall occurred by chance was quite high, about 0.14. This value was obtained from a sign-rank test which made use of a ranking of the differences of the mean rainfall of pairs of days. A comparison of the extreme rainfalls on seeded and non-seeded pairs of days was made by taking the differences of the maximum rainfall at any station. The heaviest rains fell most frequently on the seeded days. A sign-rank test showed that the probability of observing the observed differences if the observation was produced by chance was 0.06. This value

is still too high to permit a conclusion that the results were brought about by the seeding, but they certainly suggest that the AgI nuclei may have produced some changes.

Heights of thunderstorms. -- An objective way to measure the relative frequencies of large thunderstorms is to take radar observations every 30 minutes and note whether there is at least one cloud extending above any particular altitude. When this was done, it was found that during the seeded days there were about twice as many echoes extending above 30,000, 35,000 feet and 40,000 feet (see Table 1).

Table 1. Frequency of observations with thunderstorms exceeding the indicated altitudes (in thousands of feet)

	Seeded				Not Seeded			
	≥30	≥35	≥40	≥45	≥30	≥35	≥40	≥45
1957	20	14	9	2	10	8	5	2
1958	25	17	7	1	19	6	2	0
Total	45	31	16	3	29	14	7	2

A sign-rank test in this instance showed that the probability that the differences in the number of clouds extending above 30,000 feet occurred by chance was 0.05.

Lightning. -- Lightning observations were not taken in 1957. However, in 1958 it was found that on the seeded days there were about nine times more lightning strokes than on the not-seeded days (see Table 2). A sign-rank test revealed that the probability of chance occurrence of the observed ranking of the differences of strokes on pairs of days (last column, Table 2) was about 0.015. It was interesting to find that, notwithstanding the large difference in lightning frequency, there was little or no difference in the

Table 2. Visually-observed lightning strokes

SEED		NO SEED		Diff.
Date	No.	Date	No.	S-NS
July 17	15	July 16	0	+15
18	0	19	0	0
24	0	25	95	-95
31	0	30	0	0
Aug. 2	0	Aug. 1	2	-2
4	2	5	0	+2
6	74	7	0	+74
12	0	13	0	0
14	747	15	0	+747
16	0	18	2	-2
19	174	20	20	+154
21	48	22	0	+48
25	6	23	0	+6
28	9	27	0	+9
29	71	30	0	+71
Sept. 4	119	Sept. 3	19	+100
Totals	1265		138	+1127

number of lightning-caused forest fires (see Table 3). One might offer the explanation that the higher lightning frequency was offset by more rain which reduced the likelihood of the formation and spread of fires.

Table 3. Frequency of lightning and lightning-caused forest fires

		S	NS
1957	Lightning	?	?
	Fires	0	3
1958	Lightning	1,265	135
	Fires	3	4

Initiation of precipitation. -- By means of the cloud camera and radar data, it was possible to note the vertical extent of clouds (and thus cloud-top temperatures) and whether or not they contained precipitation. When a sufficient number of clouds have been examined it becomes possible to speak of the "probability of precipitation" of clouds whose summit temperatures are between -12 and -18 C., or any other temperature interval. Figure 2 shows a summary of the observations made during 1957 and 1958. The smoothed solid and dashed curves were drawn in by eye. It can be seen that on the seeded days the likelihood of precipitation was greater than on the non-seeded days. The fairly uniform shift of the curve towards the left lends support to the assumption that the effect is real, and that, in fact, the AgI seeding caused the formation of precipitation in clouds which would not have precipitated naturally.

If the nearly straight parts of the curves are extended to the abscissa (dotted lines), it is found that the "not seeded curve" intercepts the abscissa at about -17° C. It might be argued that this result is reasonable because observations of ice nuclei in the atmosphere show that in general the

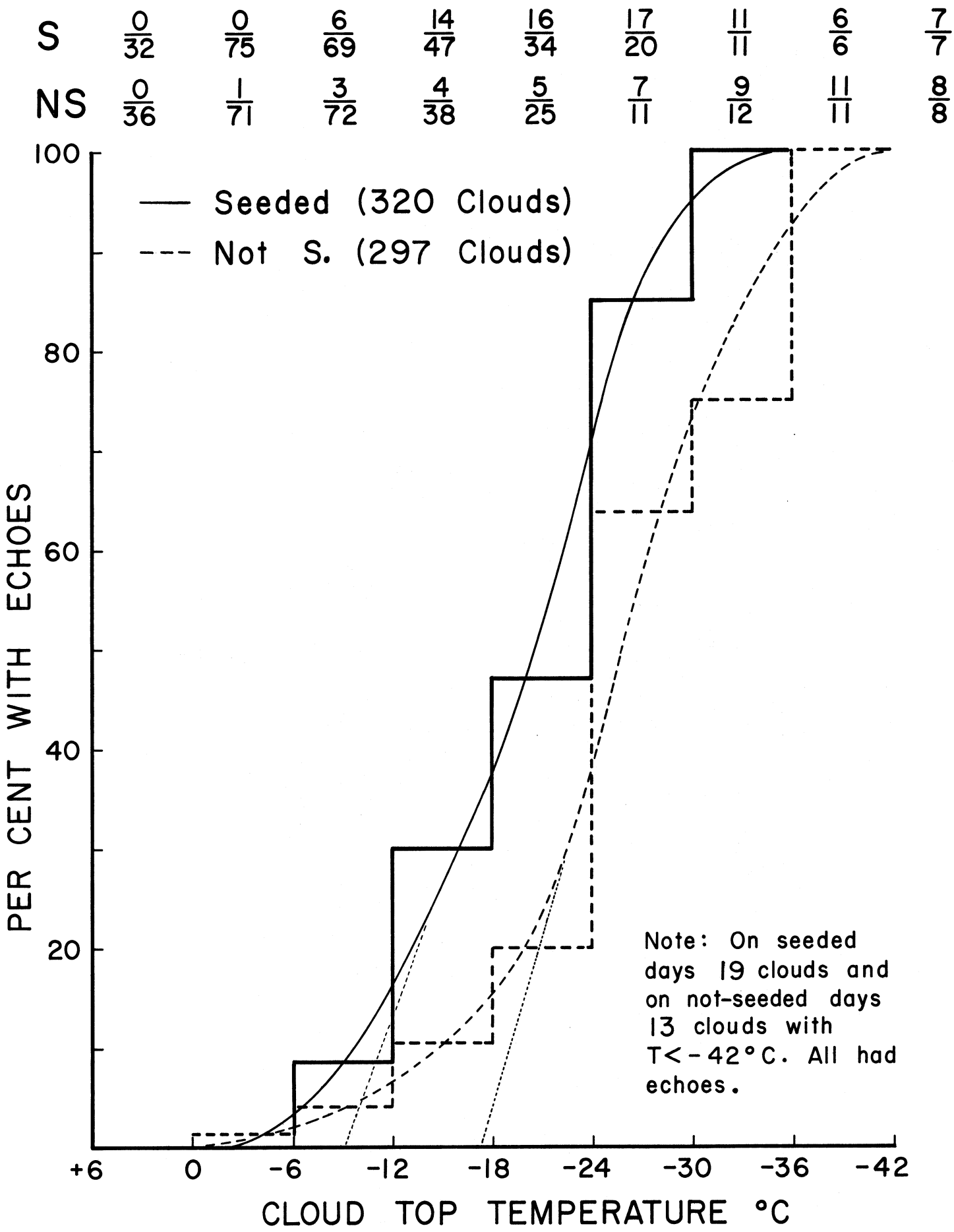
S 0/32 0/75 6/69 14/47 16/34 17/20 11/11 6/6 7/7
NS 0/36 1/71 3/72 4/38 5/25 7/11 9/12 11/11 8/8
Seeded (320 Clouds)
Not S. (297 Clouds)
PER CENT WITH ECHOES
100
80
60
40
20
+6
0
-6
-12
-18
-24
-30
-36
-42
CLOUD TOP TEMPERATURE °C
Note: On seeded days 19 clouds and on not-seeded days 13 clouds with T<-42°C. All had echoes.

Figure 2

concentrations at temperatures above -15° C. are small. As the temperature is reduced the concentration increases. It appears reasonable to assume that the dotted-dashed curve represents clouds in which the ice crystal mechanism was effective in causing precipitation.

An extension of the "seeded curve" shows that it intercepts the abscissa at about -9° C., a temperature just below the value at which AgI crystals can be expected to become effective as ice crystal nuclei.

If the interpretations of the significance of the dotted curves are correct, then one is led to the assertion that those precipitating clouds which fall to the left of the projected curves produced the precipitation by the condensation-coalescence process.

5. Summary

The results of experiments conducted during the first two summers strongly suggest that the AgI seeding produced some important effects. The fact that in both years of operations the observed differences were in the same direction, would suggest that the observed effects were produced, at least in part, by the introduction of the AgI nuclei. However, on the basis of the statistical tests one must still admit the possibility that the results were brought about by chance. The continuation of the program should permit the accumulation of sufficient data to answer, in very definite terms, whether or not the results observed were caused naturally or artificially.

6. References

Battan, L. J., and A. R. Kassander, Jr., 1958. Randomized Seeding of Orographic Cumuli, 1957. Part I. Tech. Note No. 12, Dept. Meteor., Univ. Chicago, 17 pp.

Kassander, A. R., Jr., and L. L. Sims, 1957. Cloud Photogrammetry with Ground-Located K-17 Aerial Cameras. J. Meteor., 14, 43-49.