NOTE ON THE WEATHER BUREAU ACN PROJECT

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1. Introduction

The purpose of this note is to provide information on the Weather Bureau ACN Cloud Seeding Project relevant to the discussion in our main paper [1], pp. 293–325, which is too long to be included in the paper itself. The source of the information is the article by Ferguson Hall published in *Meteorological Monographs* [2].

2. Experimental area

The project experimental area was in the states of Washington and Oregon. It was bounded on the west by the Pacific Ocean, on the east by the ridge of Cascade Mountains, on the north by the southern edge of the Olympic Mountains including the Puget Sound area, and on the south it extended a short distance into northwestern Oregon. The approximate dimensions are 200 miles in a north-south direction and about 130 miles east-west.

3. Seeding

Cloud seeding was done with dry ice dispensed from aircraft flying across the direction of the advancing winter type storms, which are usually from the west. The seeding line varied in length from 20 to 40 miles. The intention was to seed only cloud systems that were "ripe for seeding." The decision as to whether a particular storm system was to be a "test unit" was reached using synoptic data and observations made from an aircraft exploring the atmosphere upwind from the experimental area. The test units were randomized with probability for seeding equal to 2/3. A total of 141 flights of all types were made. Sixty of these were operational weather flights made in anticipation of seedable conditions. The conditions were declared seedable on only 35 of these cases and randomization resulted in 22 seeding and 13 control cases. As emphasized by Hall, and as is perfectly reasonable to expect, mistakes in diagnosing seedability are unavoidable and some of the 35 test cases did not really have much "seeding potential."

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4. Targets

Three types of targets were considered, all representing those sections of the general experimental area where the seeding was expected to have the greatest effect. For each test case, the targets were adjusted after the completion of the experiment, in accordance with prevailing winds.

"Type I target areas were truncated sectors, bounded upwind by the seeding line and downwind by the edge of the raingage network, in a direction governed by the mean wind direction between the melting and seeding levels. To allow for possible spreading of seeding effects, each side was allowed to diverge 10° from lines parallel to the target area axis."

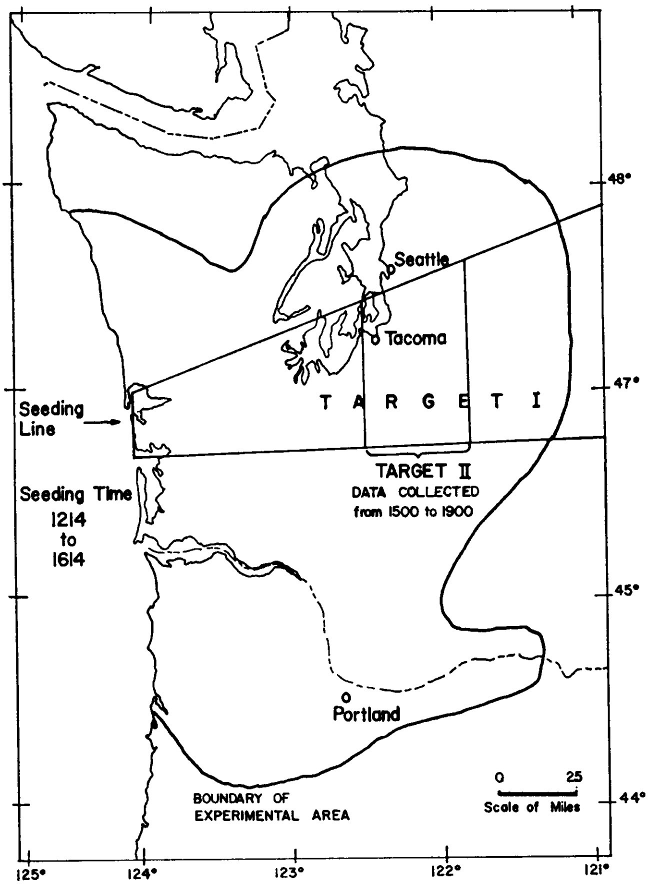

FIGURE 1

Illustration of targets I and II and experimental area in ACN experiment (adapted from [2]).

Type II targets were sections of targets I of length equal to approximately one hour of wind travel. They were centered at "a distance from the seeding line judged to provide the greatest sensitivity to cloud seeding." The definitions of targets I and II are illustrated in figure 1.

Type III targets differed considerably from the first two. Also intended to include the location of the greatest effect of seeding, they were defined by a combination of 14 rules, too complicated to be reported in this note. Although containing approximately the same number of raingages as targets II, targets of type III appear to have been substantially wider.

The evaluations performed for these three types of targets used precipitation amounts quite elaborately calculated so as to include rainfall affected by seeding and no other. For example, when considering targets I, during the first hour of seeding only some of the gages were taken into account, those closest to the seeding line. During the second hour this first group of gages was supplemented by a second group which was believed to contain the effects of seeding during that period, as judged by wind velocity, and so forth.

For each target, all of the experimental area lying outside of this target constituted the "control area."

Using the three types of target, six different evaluations of effectiveness of seeding were performed.

5. Evaluation methods

The six different methods of evaluation used by Hall were based on "anomalies." For each raingage in the given target the amount of "natural" test period rainfall was estimated. Then this estimate was subtracted from the actual rainfall recorded for the test period. The difference so obtained represented the "anomaly" for the given raingage. These anomalies were then averaged over the target area for each seeding and for each control operation, yielding target anomalies. The six methods of evaluation differed in the way the normal precipitation for a given raingage and the given test period was estimated, some of them very complicated and all raising questions.

The following general remarks occur to us. The observations that one can obtain directly from raingages reflect two things: (a) the actual rainfall in the given locality and (b) the properties of the measuring procedure, including the properties of the gage, of its location and of the reading method. The analysis of a weather modification experiment is concerned with point (a) and the influences of point (b) are noxious. However, these noxious influences are unavoidable. The calculations by the several methods of Hall deal with "anomalies" which are subject to a third source of variation, say (c), represented by a multiplicity of arithmetical operations performed separately on *each particular raingage reading.*

The relation of this arithmetic to the precipitation phenomenon is obscure, and we feel that the influence of extraneous elements on the final values of the

TABLE I

OBSERVATIONAL RESULTS OF ACN EXPERIMENT [2]

Average target rainfall for type I applies to method 2 only; for type II it applies to methods 1, 3, 4 (values for method 5 differ slightly); for type III it applies to method 6 only.

Date	Duration (hr)	Number of Target Stations			Average Target Rainfall (inches per 4 hr)		
Seeding cases		Type I	Type II	Type III	Type I	Type II	Type III
1953 Mar. 24	2	34	7	4	.1218	.0200	.0000
Apr. 13	3	44	16	9	.0403	.0163	.0252
Apr. 16	2	18	5	4	.1166	15.60	.1667
Oct. 9	3	21	11	10	.2375	.2885	24.93
Nov. 4	2	18	7	7	.1256	.1458	.1048
Nov. 11	3	26	14	11	.1400	.1019	.0691
Nov. 13	3	14	9	6	.2439	.1867	.1633
Nov. 18	4	53	6	19	.0072	.0233	.0383
Dec. 1	3	44	10	9	.0707	.1067	11.41
Dec. 4	4	36	9	9	.1036	.1011	.1831
Dec. 11	3	37	19	24	.1632	.2407	.1167
Dec. 23	2	33	6	11	.0788	.0666	.0691
Dec. 31	3	27	8	8	.0365	.0133	.0688
1954 Feb. 11	3	29	11	12	.2409	.2897	.3083
Feb. 12	3	34	21	12	.0408	.0425	.0800
Feb. 15	4	24	11	7	.2204	.2191	.4295
Feb. 18	3	34	12	11	.1847	.0789	.3655
Feb. 20	4	31	10	11	.3332	.3570	.4555
Apr. 2	4	25	5	8	.0676	.0760	.0510
Apr. 4	4	31	8	9	.1097	.0913	.0942
Apr. 5	1	13	3	5	.0952	.0400	.0880
Apr. 12	3	31	11	13	.2095	.1467	.1471
$N = 22$				Average	.1358	.1276	
Control cases							
1953 Apr. 8	4	10	1	3	.0080	.0000	.0000
Apr. 26	4	24	2	5	.0046	.0000	.0048
Sept. 26	3	34	10	11	.0059	.0053	.0045
Oct. 17	3	46	10	12	.1313	.0920	.1380
Nov. 5	4	15	5	4	.0587	.0220	.0180
Nov. 25	3	48	10	13	.1723	.1133	.0823
Dec. 9	1	38	10	12	.3812	.2880	.2917
1954 Jan. 20	4	5	1	5	.1720	.0000	.0380
Feb. 13	2	33	14	8	.1182	.1058	.0983
Feb. 16	4	18	10	6	.1383	.2050	.0133
Mar. 15	4	16	8	6	.0106	.0100	.0160
Mar. 26	4	38	6	11	.2126	.2450	.2022
Apr. 7–8	4	20	7	9	.1435	.1529	.0524
$N = 13$				Average	.1198	.0953	

anomalies may well overshadow the relationship of these anomalies to the phenomenon of precipitation that is the subject of study.

As we see it, the most reliable rainfall observations are the direct readings of precipitation records made over some reasonably long, fixed period of time, averaged over a fixed network of gages, perhaps with the use of a fixed system of weights.

6. Numerical results

Table I reproduces observational data as published by Ferguson Hall. Table II gives the summary of his six evaluations. A remarkable feature of table I

TABLE II

STATISTICAL SUMMARY OF ACN EXPERIMENT

Method	Average Target Rainfall (inches per 4 hr)	Average Rainfall Anomaly Observed Minus Estimated (inches per 4 hr) Seeding	Control	Difference in Anomalies Seeding Minus Control (inches per 4 hr)	Per cent Increase or Decrease	t test Ratio	Probability (two tail)
1	.1298	.0171	.0214	−.0043	−3.3	−0.195	>0.8
2	.1156	.0144	.0002	.0142	12.28	0.470	>0.6
3	.1298	.0181	.0186	−.0005	−0.39	−0.040	>0.9
4	.1298	.0037	.0029	.0008	0.62	0.047	>0.9
5	.1290	.0110	−.0198	.0308	23.88	1.759	0.08
6	.1254	−.0210	−.0215	.0005	0.40	0.019	>0.9

should be mentioned. In the triple column under the heading "Average Target Rainfall," Hall gives average amounts of precipitation separately for seeded and for control test units. This is done for targets I and targets II only.

	Targets I	Targets II
Average seeded	0.1358	0.1276
Average control	0.1198	0.0953

It is seen that for both types there is a sizable difference in favor of seeded test units, amounting to 13 per cent of the control precipitation in one case and to 34 per cent in the other. However, no such averages have been published by Hall for type III targets. Yet, they are very impressive: 0.1540 for seeded and 0.0736 for control test units, the former exceeding the latter by more than 100 per cent. Not only are the average precipitation amounts for targets III not published, but also we failed to find in Hall's paper any relevant comment. As a result, we have the feeling that, for some reason, Hall intended to deemphasize targets III. A possible clue to the reasons for this apparent lack of comfort with targets III is contained in the description of the times used in the definition of the three types of targets and in the development of methods of evaluation. Some subjective bias may have occurred. One of the relevant remarks of Hall reads as follows: "Methods (of evaluation) 1 and 2 may be considered most objective, since they were performed first and corresponded closely to the procedure envisioned ahead of time."

Since the timing of possible effects of seeding over particular sections of the experimental area must be a very hazardous undertaking and since the basic question is whether the seeding can modify the precipitation reaching the ground, the Statistical Laboratory attempted to locate the original data on precipitation amounts as recorded by particular gages, but was not successful. The attempt at a reevaluation had to be based on figures in table I relating to the three different targets. For each target the data were treated as having been obtained by a fixed method, independent of the precipitation fallen, with a random selection of units subject to seeding. The results of this evaluation are given in table I in the main body of our paper [1], p. 297.

REFERENCES

[1] J. Neyman and E. L. Scott, "Some outstanding problems relating to rain modification," *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability*, Berkeley and Los Angeles, University of California Press, 1967, Vol. 5, pp. 293–325.

[2] F. Hall, "The Weather Bureau ACN Project," *Meteor. Monogr.*, Vol. 2 (1957), pp. 24–46.