"REVIEWED"

ASSESSMENT OF SUMMER 1979 WEATHER MODIFICATION EFFORT IN SOUTHEASTERN ILLINOIS

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Abstract. An operational cloud seeding project took place in southeastern Illinois during a 40-day period in the summer of 1979. A historical target-control evaluation design, using NWS raingage data, indicated an estimated rainfall increase of 39.5% in the target. Three statistical evaluation techniques - principal component regression, multiple regressions and double ratio, were employed and compared. The (randomization) significance levels were .10, .26, and .26, respectively. The possibility of the east control being contaminated was studied and found rather unlikely. Investigation of the 1979 isohyetal pattern, based on a 92-raingage network data revealed that within the target there were wide extremes, from very low to very heavy, and a localized high existed in the target on seeded rain occasions which was not present on no-seed rain occasions.

1. INTRODUCTION

During the dry summer of 1978, a group of citizens in southeastern Illinois became interested in the possibility of obtaining additional rainfall through the use of a weather modification program. By the latter part of the summer, they had formed a corporation called Southeastern Rain Incorporated; raised funds, and launched a cloud seeding project carried out by a weather modification firm in August and early September. No scientific assessment of this hurriedly assembled effort was attempted. The regional interest in this endeavor, and the potential for agricultural benefits deriving from additional summer rainfall in this area of Illinois, led the group to plan for a second summer season project in 1979. During the spring of 1979, a local fund raising program was conducted.

Interactions between the local county cooperative extension advisors and staff of the Illinois State Water Survey, which was providing scientific and technical information on weather modification, led to the decision that the State Water Survey would plan and perform an assessment of the rainfall during the 1979 project. This would provide information to local groups and state officials, and also test evaluation techniques and concepts being evolved on an NSF-sponsored project concerned with operational projects.

Survey officials discussed the needs for rainfall data with county extension advisors. This led to the establishment of a network of 92 raingages in a 6-county area embracing the 1979 "target area" (Figure 1) of about 2600 sq km. The Target Area was defined as that area in which funds were raised and was identified as the site for cloud seeding operations, based upon the contract between Southeastern Rain Inc., and Atmospherics Incorporated, the company contracted to do the 1979 cloud seeding project. The Target Area embraced most of Saline and Gallatin Counties, and parts of Franklin, Hamilton, White, and Williamson Counties. Plastic raingages were obtained, and given to farmers who were to serve as observers of daily rainfall amounts.

Results from this 1979 cloud seeding effort are presented and assessed. It is *important* to appreciate that the assessment of the 1979 summer rainfall, which involved comparisons of the rainfall pattern and amounts in the Target (seeded) area with those in the surrounding (non-seeded) areas, is not to infer *conclusively* that the rainfall in the Target was either increased or decreased because of seeding. We *stress* that it is very unlikely due to the great natural variability of summer rainfall in southern Illinois, that one could decide whether cloud seeding during a period of a few weeks altered the rainfall.

Rather, these statistics are presented with these *cautions* to achieve our objectives which are: 1) to describe the rainfall in and around the Target Area, and 2) to compare three of many statistical evaluation techniques being investigated by the authors (Changnon et al., 1980). The second objective is emphasized here in interpreting the subsequent analyses. From a scientific standpoint, these data will hopefully become a part of a larger bank of data, including radar echo data and cloud seeding operational data for 1979 (and subsequent years and other projects), which ultimately may provide sufficient information to allow some assessment of whether cloud seeding in Illinois actually 1) altered clouds and their behavior, and 2) altered rainfall *with some high degree of certainty*.

2. DATA

By the middle of June 1979, a reasonably dense network of 92 non-recording raingages had been installed, largely within the Target Area, Figure 1. Although the 92 raingages in the raingage network were not evenly distributed, the network represents a much denser sampling of rainfall than would be obtained without the network.

The official raingages of the National Weather Service in the area are shown on Figure 1,

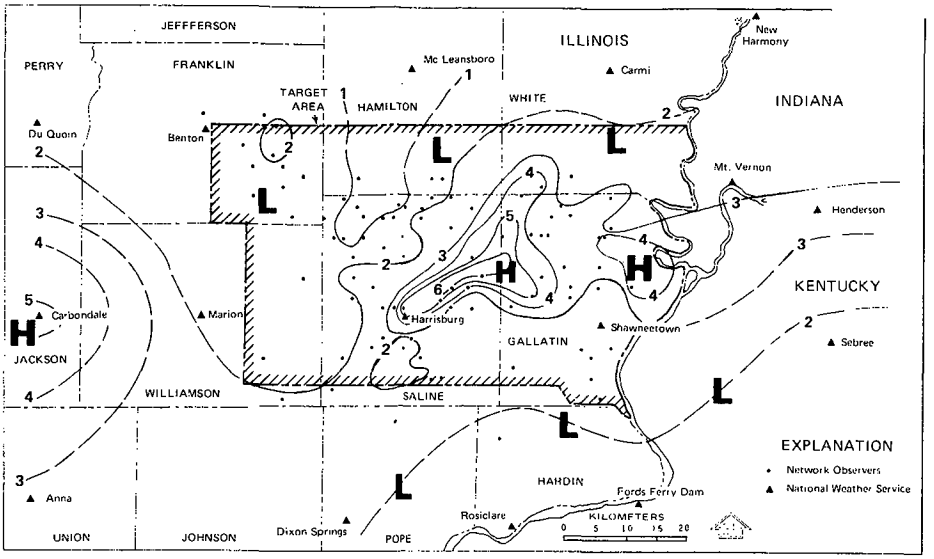

Figure 1. Rainfall (inches) from rains when cloud seeding occurred.

each denoted by a small triangle. Typically, there is only one such station per county in this region of Illinois and Kentucky.

Rainfall at these National Weather Service stations and at the 92 raingages operated by the local volunteer observers in the special network was measured once daily, typically at 0700 or 0800 CDT. Data were collected from the middle of June (prior to the start of cloud seeding) until late August (several days after operations terminated). Daily rainfall observations of the cooperative observers were entered on postcards, mailed to the county extension advisors, who in turn transmitted the data to the Illinois State Water Survey. The daily rainfall data of the National Weather Service observers in the area of interest were available in the published records of that agency. These two data sets were used for assessing the summer 1979 rainfall distribution in the Target.

The cloud seeding company was available and ready to seed clouds from 23 June through 26 July 1979, and then, after a pause because local conditions were too wet with lowland flooding, the operations were available again from 10 August through 15 August 1979. Thus, cloud seeding could have been conducted, if suitable weather conditions were available, for a period of 40 days within this 23 June-15 August period. This period of 23 June-26 July and 10 August-15 August was called the operational period.

3. ANALYSIS

In the following, we first looked at the 1979 isohyetal patterns based on the network of observer gages as well as the National Weather Service stations during the operational period. The purpose of this initial analysis was to reveal any unusual rainfall patterns on an exploratory-data-analysis sense. Subsequently, we conducted historical target-control comparison using only the National Weather Service station data from 1949 to 1979 in and around the Target Area. All NWS stations used possess continuous rainfall records during the 31-year period.

3.1 The 1979 Isohyetal Patterns Based on Dense Raingage Network

Daily rainfall values were classified according to three types of operational decisions by the weather modification group which operated its radar and seeding aircraft at the Marion Airport. Rainfall data from days when cloud seeding occurred during all or a portion of the rain in the Target Area, became the "seeded" rainfall amounts. These included six occasions: 23-24 June, 29 June, 30 June, 8-9 July, 10 July, and 12-13 July. The rainfall at each of the observer gages and at the National Weather Service gages for these six occasions were totaled and identified as the "seeded rains only."

It is important to realize that it rained on other occasions during the operational period. There were 17 rain occasions identified that classified as "non-seeded rains." The reporting forms from the cloud seeding operations indicated that these could be further subdivided into two classes. First were those when there were no cloud seeding but when the seeding airplanes flew to observe and measure clouds to see if they were amenable to seeding. This inferred that the project meteorologists believed atmospheric conditions suitable for successful seeding existed, and had the pilots go aloft to monitor conditions. However, the pilots concluded in these cases that the clouds were not right. The second class comprised eight rain occasions when there was no flying. These were situations in which the project meteorologists considered the conditions were totally unsuitable for rainfall modification.

These three categories of the rainfall during the 1979 operational period were further developed into five classifications:

1) Rainfall from these rain occasions when cloud seeding occurred (6 rain occasions).
2) Rainfall from the non-seeded rain occasions but when aircraft cloud observations occurred (9 rain occasions).
3) Rainfall from the non-seeded rain occasions with no cloud observations (8 rain occasions).

4) Rainfall from both of non-seeded rain occasions (a total of 17 rain occasions).

5) Rainfall from all rain occasions (a total of 23 rain occasions).

The pattern from the total rainfall in the six occasions with cloud seeding is shown in Figure 1. A small but well-defined high rainfall area occurred in the center of the Target Area. Low rainfall values fell in the northern and western parts of the Target Area, rainfall almost as high as in the center of the Target is found to the west, centered at Carbondale. The area embraced by the 3-inch isohyetal line extends from near Harrisburg eastward well beyond the Target Area into southwestern Indiana and western Kentucky.

The isohyetal map of the rains when no cloud seeding occurred *but* when aircraft cloud observations were made (Figure 2), shows a rain pattern similar to that of the seeded rainfall (Figure 1). A rainfall high is in the center of the Target Area and extends eastward beyond the Target. However, greater rainfall highs are found to the southwest of the Target. In general, the pattern is remarkably similar to the seeded-occasion pattern, and the rainfall totals, in general, are comparable at many locations to those for the seeded occasions.

Figure 3 presents the pattern of rainfall on the eight non-seed occasions without airborne cloud measurements. These reflect atmospheric conditions that were considered totally unsuitable for cloud seeding well before the rain began and during the rain. The pattern of these non-seed rainfall occasions is somewhat similar to those of the seed and the other non-seed occasions with cloud observations. A generalized west-east high crosses the Target Area, but farther south. Rainfall in the center of the Target Area is much lower than in the seed category, although rainfall values in the northern part of the Target

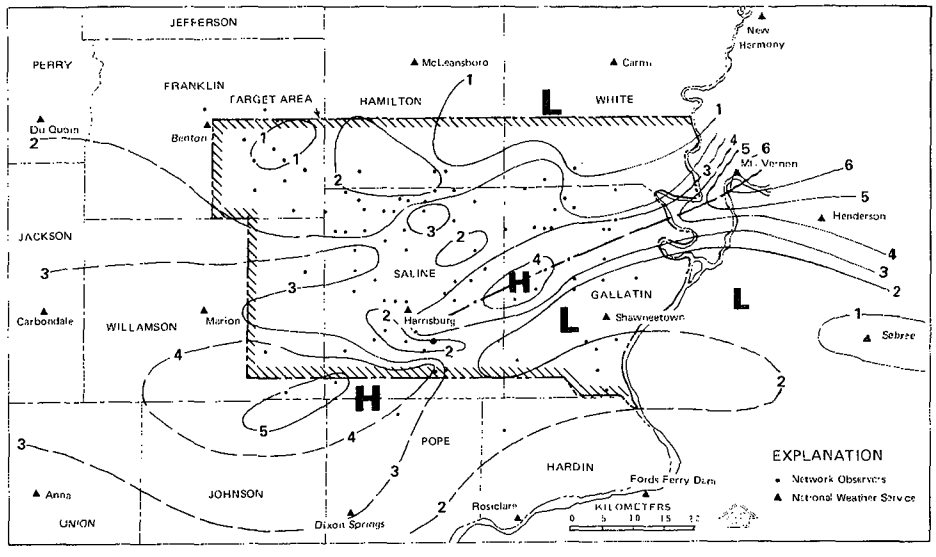

Figure 2. Rainfall (inches) from rains without cloud seeding but with aircraft cloud observations.

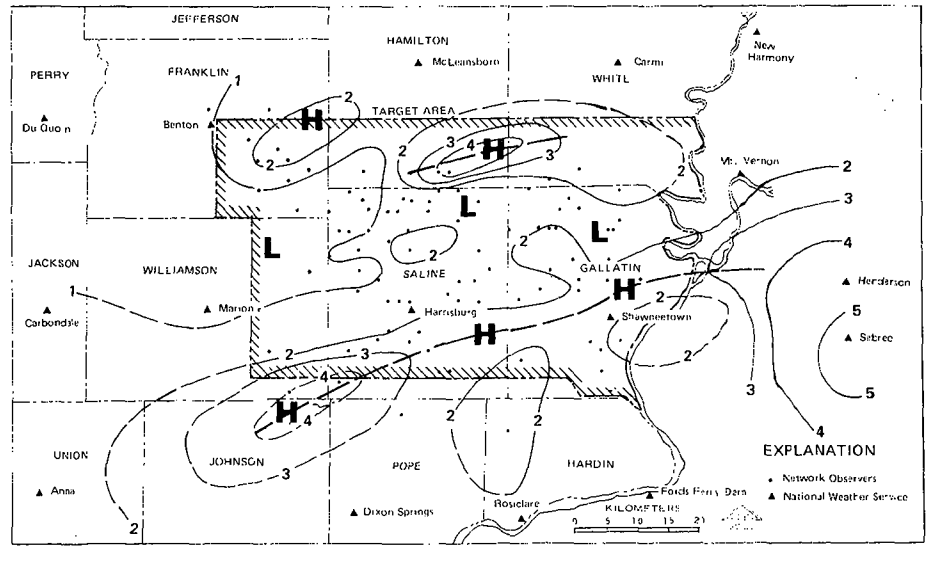

Figure 3. Rainfall (inches) from rains without cloud seeding or cloud measurement.

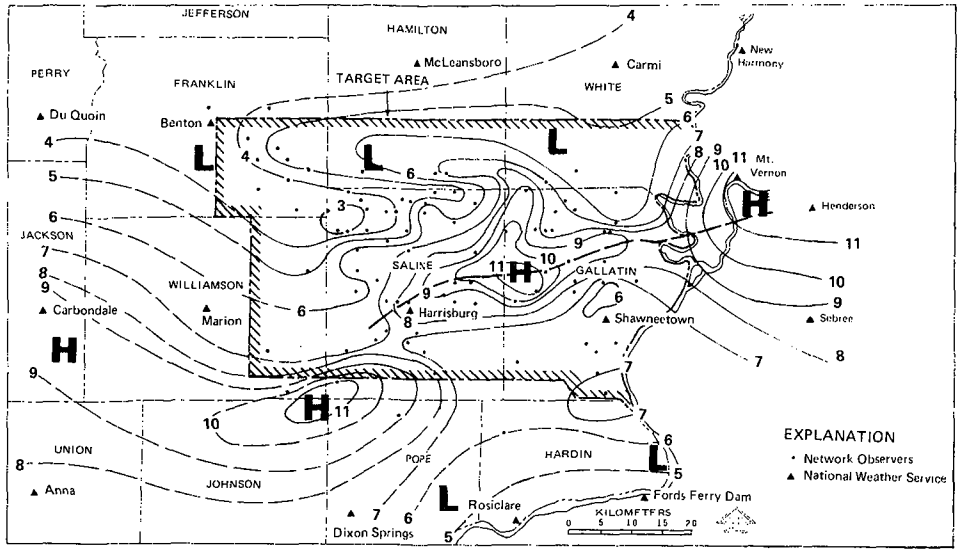

Figure 4. Total rainfall (inches) in 1979 period of weather modification.

Area (Franklin, Hamilton, and White Counties) are higher in this non-seed category than in the seed category or in the non-seed/cloud observation category.

Combining the values from the three categories of rain occasions gives the total rainfall for the 40-day operational period (Figure 4). A west-east oriented ridge of heavy rainfall runs from Carbondale to the southwest corner of the Target Area and then ENE across the center of the Target. It reaches a maximum of 11 inches (280 mm) between Harrisburg and Shawneetown and then extends eastward into Indiana and Kentucky, where amounts greater than 11 inches (280 mm) also occurred. Rainfall values in the Target Area ranged from less than 3 inches (76 mm) in one locale between Benton and Harrisburg, to as much as 11.22 inches (285 mm).

The danger of making claims for cloud seeding from inspection of rainfall patterns alone is easily demonstrated by Figure 4. One might wish to claim that the heavy rainfall centered in the Target Area was a result of cloud seeding. However, rainfall totals as high or higher outside of the Target were found to the southwest and east. Within the Target Area, in the northwest, the northern, and southeastern portions, rainfall was as low or lower than those anywhere else in the area surrounding the Target.

3.2 National Weather Service Gages

One of the problems in assessing the rainfall data for seeding effects utilizing the excellent, dense raingage network established for the Target Area relates to the fact that there was *not* a comparable raingage network and rainfall data from the surrounding areas. This becomes a problem when one wishes to evaluate the Target Area rainfall by comparing it with that in surrounding areas to derive conclusions as to its relative magnitude. That is, was the Target rain higher or lower than one might have expected? A time-honored approach to rainfall evaluation of a specific area has been to compare the rainfall in a Target Area with that in climatologically homogeneous regions nearby. The nearby regions are typically called "control areas" for comparison with the "Target Area."

In order to make a fair comparison considering different raingage densities, the rainfall data from only the available National Weather Service (NWS) raingages in and around the Target Area were used. The only NWS gages in the Target Area were at Harrisburg and Shawneetown. Prior to the seeding project (in early June 1979), control areas to the north, west, south, and east of the Target Area were defined and each included two or three National Weather Service gages. The groupings of these gages according to the various controls are shown in Table 1. For example, the North Control Area comprised the rainfall values from the station gages at McLeansboro and Carmi. In essence, the four control areas surrounding the Target Area are shaped, at least conceptually, as shown by the four boxes in Figure 5. They are areas of a size equivalent to the Target Area, and each has the same general raingage density of approximately one gage per 1300 sq km.

3.2.1 1979 Target-Control Comparisons. Rainfall totals were defined to be that total during the operational period (June 23 to July 26 and August 8-15). Table 1 shows the total rainfall values at each of these stations for the five classifications of rainfall. The station values (under the five rain categories), in the Target and in the four control areas, were combined to form areal averages. The areal averages are plotted in the map portrayals (Figure 5) to permit easier comparison and reveal differences between regions. For example, on the seed occasions (Figure 5a), one finds the Target areal average of 3.50 inches (89 mm) with lesser area averages in all of the 4 surrounding control areas. The average of all 4 control areas was 1.91 inches (49 mm), and the difference between target and control average, labeled T-C (or target minus control), is equal to 1.59 inches (40 mm). This difference, expressed as a percent of the control average, represents 83.2% more rainfall in the Target than in the Controls.

Similar comparisons for the two non-seed rain categories appear as Figure 5b and 5c. Both

show that the Target Area received less rainfall, than did the average of the four control areas. It was 11.4% less in the cloud observation/non-seed category, and 28.3% less in the non-seed rains with no cloud observations.

Figure 5d presents the areal average rainfall values combined for both categories of non-seed conditions. One sees here that the Target Area received more rainfall than did the North, West, and South Control Areas, but noticeably less than did the East Control Area. The difference between the four control areas and the Target represents 0.90 inch less, or 19.4% less rainfall in the Target than in the surrounding control areas. It is important to note that rainfall in the East Control Area in both of the non-seed categories (Figures 5a and 5c) were higher than in the Target Area.

The combination of all the 1979 rains in the operational period is shown in Figure 5e. The Target Area rain of 7.24 inches (184 mm) easily exceeds the averages of the North, West, and South Control Areas but is considerably less than the East Control Area. The four control areas had an average rain of 6.20 inches (157 mm). The target/control ratio is thus 1.17, a crude indication of more rainfall in the Target Area than the control areas. (For all gages the ratio is 7.24/6.55 = 1.11.) However, this ratio cannot be used alone as indication of any seeding effect, as certain "selection bias" may have been introduced by the seeding operator in favor of more natural rainfall on days chosen for seeding. More reliable and more bias-free evaluation involves use of the historical target-control comparison.

3.2.2 Historical Target-Control Comparison, All Controls. The area precipitation values from 1949 to 1978 were used as historical observations. Three statistical evaluation techniques were chosen before the actual evaluation efforts were undertaken, namely, the principal component regression (PCR), multiple regression (MR), and double ratio (DR). The choice of evaluation techniques were largely based upon findings from an NSF-funded research, which investigated performance of various statistical-physical techniques in evaluating operational weather modification projects (Changnon et al., 1980; Hsu, 1979). The decision to use three techniques undoubtfully will raise the question of multiplicity, but the evaluation efforts are basically exploratory, rather than to confirm the effectiveness of cloud seeding over southeastern Illinois.

1. Principal Component Regression. First, a principal component analysis for the four control areas using 1949-1978 historical data was performed and the first three components were retained, which were used in turn as independent variables to run a regression on the Target Area value. The principal component regression equation thus derived was used to

Table 1. Rainfall Totals at National Weather Service Raingages, Operational Period, Southeastern Illinois 1979 Cloud Seeding Project.

		Seeded	Cloud Flights	No Cloud Flights	Both	Total Rainfall
	Occasions	6	9	8	17	23
Target Area						
Harrisburg		4.35	2.79	1.13	3.92	8.27
Shawneetown		2.65	1.54	2.02	3.56	6.21
	Average	3.50	2.17	1.57	3.74	7.24
North Control Area						
McLeansboro		0.63	1.47	1.21	2.68	3.31
Carmi		1.95	0.90	1.55	2.45	4.40
	Average	1.29	1.19	1.38	2.57	3.86
West Control Area						
Benton		1.51	1.19	1.00	2.19	3.70
Marion		1.87	3.57	0.87	4.44	6.31
	Average	1.69	2.38	0.94	3.32	5.01
South Control Area						
Dixon Springs		2.13	3.11	2.32	5.43	7.56
Rosiclare		1.30	1.06	2.03	3.09	4.39
Fords Ferry		1.80	1.34	1.22	2.56	4.37
	Average	1.74	1.84	1.86	3.69	5.44
East Control Area						
Mt. Vernon		2.96	6.89	1.84	8.73	11.69
Henderson		3.09	4.09	4.40	8.49	11.58
Sebree		1.90	0.85	5.45	6.30	8.20
	Average	2.65	3.94	3.90	7.84	10.49

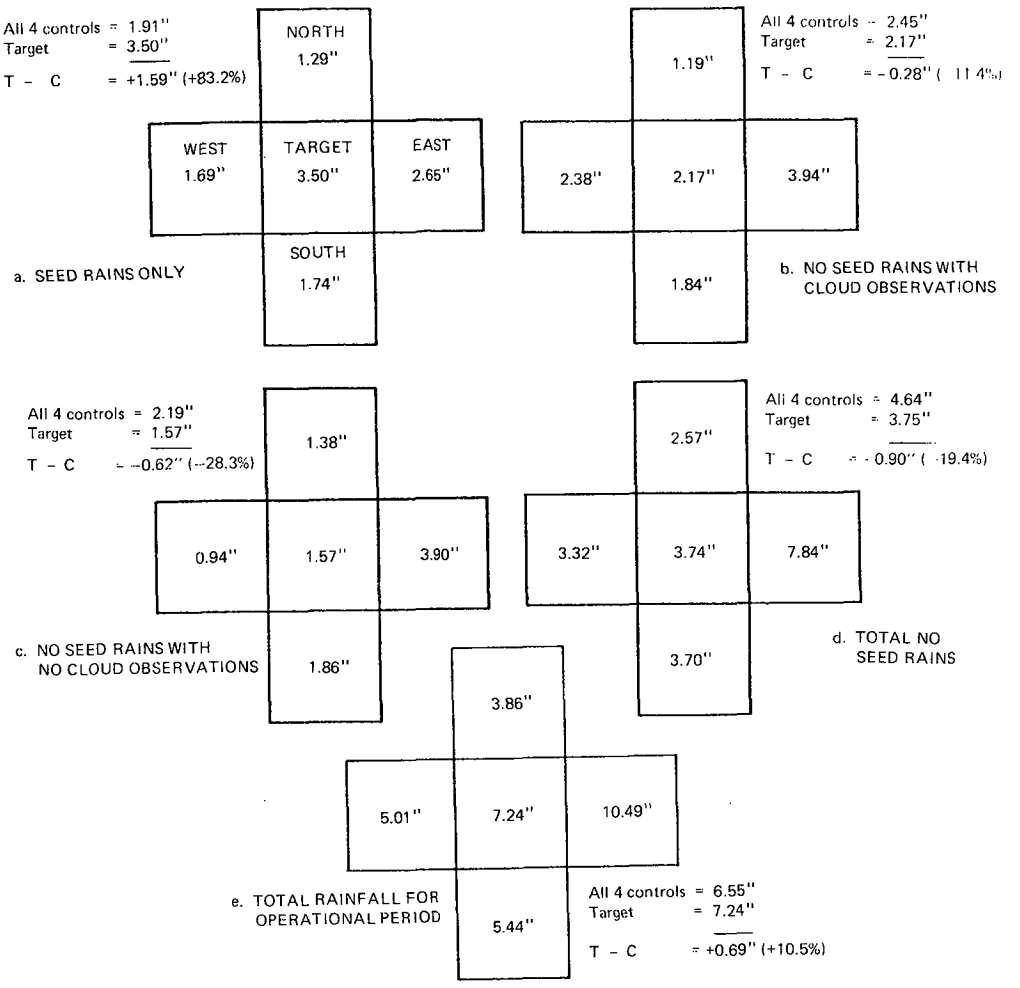

Figure 5. Area mean rainfall in target and control areas during the Southeastern Illinois Cloud Seeding Project in 1979 Values are based on NWS data.

predict 1979 Target Area rain, which was then compared to the actual 1979 Target Area rain. The use of three components in the regression is also due to findings from the same research. The resulting predicted rain for the 1979 Target Area by using 1949-1978 PCR equation is 5.19 inches (132 mm). The difference between this and the actual rain value, (7.24-5.19), gives an estimated rainfall increase of 2.05 inches (52 mm), or 39.5%.

To assess the significance of this rainfall increase, a randomization principal component regression was performed. One year from 1949 to 1978 was selected as a hypothetical "seeded"year, and all other years (including 1979) as historical "control" years. Then a principal component regression was performed on this seeded-historical setting, a predicted precipitation was obtained, and a rainfall increase was computed.

This process was repeated by selecting another year as "seeded" and so on, until a distribution of rainfall increases was obtained. A distribution of 31 estimated rainfall increases was obtained and shown in a "stem-and-leaves" display (Table 2a). Two rainfall increases are larger than the 1979 rainfall increase (indicated by an asterisk in the table); the corresponding significance level is 3/31 = 0.10. That is, the chance is about one out of ten that this sizeable increase is due to nature, rather than to cloud seeding. Although the 1979 rainfall increase is not statistically significant at the usual .05 level, due to the very short duration (one summer) of the present project, the seeding effect is usually difficult to detect than longer project, even using more powerful evaluation techniques. Therefore, this marginal significance of 0.10 reveals that the 1979 rainfall increase may not have been completely due to natural variation, but whether this is due to cloud seeding or not is far from certain.

2. Multiple Regression. The four control areas values were used as independent variables to regress on the Target Area values using 1949-1978 data. The resulting (historical) regression equation was used to predict 1979 Target rainfall. The predicted value, 6.15 inches (156 mm), and the actual 1979 Target rainfall, 7.24 inches (184 mm), give an estimated rainfall increase of 1.09 inches (28 mm), or 17.7%. A randomization multiple regression was performed similarly to that using principal component regression. Table 2b shows a "stem-and-leaves" display of the randomization dis-

Table 2. Randomization Distributions of Estimated Rainfall Increases, All Control Areas.

2a PRINCIPAL COMPONENT REGRESSION

Stem	Leaves	Cumulative No.	Cumulative %
-2.00	00,04,09	3	9.7
-1.00	08,09,19,60,67,70	9	29.0
-0.00	11,23,42,47,57,58,74,95	17	54.8
0.00	10,19,23,43,48,48,68,69,88	26	83.9
1.00	55,75	28	90.3
2.00	05*	29	93.5
3.00	03	30	96.8
4.00	12	31	100.0

2b MULTIPLE REGRESSION

Stem	Leaves	Cumulative No.	Cumulative %
-2.00	02,07	2	6.5
-1.00	00,08,08,11,40,45,54,66	10	32.3
-0.00	02,28,33,36,41,57,82,97	18	58.1
0.00	03,10,38,50,72	23	74.2
1.00	09*,19,36,47,92	28	90.3
2.00	07,69	30	96.8
3.00	63	31	100.0

2c DOUBLE RATIO

Stem	Leaves	Cumulative No.	Cumulative %
.500	94	1	3.2
.600	49	2	6.5
.700	13,16,19,48,77,91	8	25.8
.800	32,32,76,93,95	13	41.9
.900	49,87	15	48.4
1.000	06,12,24,34,43,67,79	23	74.2
1.100	41*	24	77.4
1.200	06,70	26	83.9
1.300	17,81	28	90.3
1.400	02	29	93.5
1.500	37	30	96.8
1.600	44	31	100.0

*1979 value

tribution of estimated rainfall increases using MR; the significance level is found as 0.26.

3. Double Ratio. For the 1979 seeded year, a double ratio is calculated as follows:

$$DR = TsCns/TnsCs$$

where Ts is the rainfall total of the Target Area in the year 1979, Tns is the averaged rainfall total of the Target Area in the non-seeded years (1949-1979), and similarly Cs and Cns. A randomization double ratio was performed, and a "stem-and-leaves" display of the randomization distribution is shown in Table 2c. The double ratio corresponding to 1979 is 1.141, or an estimated rainfall increase of 0.89 inches (23 mm), and the significance level is 0.26, the same as that of MR.

These three evaluation techniques give non-identical significance levels to their respective 1979 estimated rainfall increases. Only the estimated rainfall increase using PCR is marginally significant at the 0.10 level; whereas the estimated rainfall increases using MR or DR are not as significant. In other words, the technique of principal component regression indicates that the 1979 Target Area rainfall increases was more unusual than do the techniques of MR or DR. This result partially supports findings obtained by Hsu (1979) that PCR is more powerful than MR or DR in evaluating cloud seeding under weather regimes similar to the present one.

3.2.3 Historical Target-Control Comparisons, Excluding East Control Area. The Target Area had more rain than the control areas except the East Control Area (Figure 5e), where the average of 10.49 inches (266 mm) in 1979 was much above the other area rainfall values. To find out whether this large value occurred naturally or extremely (in other words, was this an outlier?), frequency distributions of the rainfall for each area are shown in Table 3 with the 1979 rainfall values marked by asterisk. The 1979 rainfall values in the North and South Control Areas were close to their respective medians; whereas the 1979 rainfall values in the West and East Control Areas were above normal (compared to their medians).

The deviation was unusually large in the East Control Area, whose 1979 rainfall value was the second largest in the 31-year period studied. This raises a question of possible extra-area seeding effects there. Some information regarding seeding operations and the meteorological conditions of the present project are available

Table 3. Ranked Distribution of Areal Precipitation, 1949-1979.

	Target	North	West	South	East
1	1.70	1.57	1.60	1.21	2.93
2	1.91	1.83	1.86	1.24	3.23
3	2.33	1.96	1.90	2.66	3.34
4	2.44	1.97	2.47	3.07	3.37
5	2.97	2.58	2.61	3.69	3.46
6	3.23	2.81	2.87	3.69	3.49
7	3.77	2.83	2.97	3.76	3.53
8	3.80	2.88	3.20	3.81	3.61
9	3.88	2.98	3.48	4.21	3.74
10	4.19	3.06	3.63	4.30	3.82
11	4.23	3.51	3.67	4.57	4.15
12	4.39	3.55	4.00	4.72	4.18
13	4.73	3.66	4.05	4.81	4.33
14	4.82	3.82	4.18	4.92	4.56
15	4.88	3.83	4.25	5.08	4.58
16	4.92	3.86*	4.28	5.42	4.87
17	4.93	4.01	4.49	5.43	5.00
18	5.06	4.18	4.54	5.44*	5.20
19	5.21	4.24	4.60	5.61	5.32
20	5.38	4.27	4.89	5.75	5.85
21	5.57	4.72	5.01*	5.78	6.32
22	5.61	4.95	5.05	6.22	7.11
23	5.71	5.13	5.08	6.61	7.31
24	6.49	5.13	5.13	6.69	7.88
25	7.01	5.64	6.08	6.89	7.94
26	7.24*	5.67	6.64	6.91	8.34
27	7.80	6.15	6.84	7.19	8.46
28	8.08	6.19	7.23	7.99	8.53
29	8.86	7.89	7.32	8.28	9.43
30	10.20	10.83	11.86	9.10	10.49*
31	10.62	12.37	12.01	13.08	11.30

*1979 value

from the operator, but they do not contain enough details. Attempts to identify any extra-area effect by examining this information is discussed later; whereas here, it was decided to exclude the East Control Area to perform another historical Target-Control evaluation. This second evaluation does not render the first evaluation invalid, rather it only serves as an auxiliary piece of information to complement the first evaluation in regard to the question of extra-area seeding effect.

Only the techniques of multiple regression and double ratio were used. (Principal component regression with three components is identical to the multiple regression in this case.) Table 4 shows the randomization distributions of estimated rainfall increases using multiple regression as well as using double ratio. The significance levels of both techniques are 0.10. The estimated 1979 rainfall increase using multiple regression is 1.94 inches (49 mm), or 36.6%. The 1979 double ratio is 1.437, or an estimated rainfall increase of 2.20 inches (56 mm).

Overall, the significant estimated rainfall increases using either all four surrounding control areas (39.5%, PCR), or using three control areas excluding the East Control Area (36.6%, MR; 43.7%, DR) were fairly close. This suggests little likelihood that the East Control Area was contaminated during the 1979 cloud seeding period. The unusually large amount of the 1979 rainfall value in the East Control Area was probably due more to natural variation than to cloud seeding.

Indeed, the radar echo overlay (provided by the seeding operator) on the seeded days were examined to discern where seeded echoes and

Table 4. Randomization Distributions of Estimated Rainfall Increases, Surrounding Control Areas Except East.

4a MULTIPLE REGRESSION

Stem	Leaves	Cumulative No.	Cumulative %
-2.00	26	1	3.2
-1.00	05,12,19,62,65,69,92	8	25.8
-0.00	04,58,63,65,66,82,86,95,98	17	54.8
0.00	02,05,05,29,73,73,87,88	25	80.6
1.00	43,58,79,94*	29	93.5
2.00	53	30	96.8
3.00	95	31	100.0

4b DOUBLE RATIO

Stem	Leaves	Cumulative No.	Cumulative %
.600	16,71	2	6.5
.700	26,85,96	5	16.1
.800	06,14,19,25,52,65,91	12	38.7
.900	00,02,22,33,42,56,97	19	61.3
1.000	54,56	21	67.7
1.100	05,80,87	24	77.4
1.200	65,78,90	27	87.1
1.300	82	28	90.3
1.400	37*	29	93.5
1.500	79,93	31	100.0

*1979 value

echo complexes moved beyond the Target. The results shown in Table 5 reveal that there is little possibility of East Control Area being contaminated. It is surprising, however, to note that the West and South Control Areas appeared to be potential areas of contamination, which suggests that the previous estimation of 1979 T-C differences as well as the statistical significance of historical T-C comparisons might be conservative than they actually were.

Table 5. Seeded Echo Motion.

Date	Seeded Echo Motion	Control Areas Possibly Affected
June 20	Unclear	W, S
June 22	Stationary	S
June 23	From Northwest	W, S
June 29	Stationary	None
June 30	From West	E
July 9	Stationary	W
July 10	Stationary	None
July 12	From East	W

4. SUMMARY

The Target Area received more rainfall (based on only two gages to determine an area average) during the 1979 40-day operational period than did the surrounding areas. This was particularly true when one compared the Target rainfall with the surrounding control rainfall based solely on the seed rain occasions. Investigation of the 1979 rainfall (isohyetal) pattern within the Target, based on the detailed 92-raingage network data, showed that there were wide extremes, from very low to very heavy rainfall in the Target Area.

The 1979 rainfall data alone cannot be construed as evidence of any cloud seeding effect. However, the differences between seeded and non-seed values, particularly as revealed in Figure 5, do suggest that a localized high existed in the Target on seeded occasions which was not present on non-seed occasions. As one final caution, one expects that cloud seeding in the Target Area would be attempted under conditions that were locally favorable for heavier rainfall there, and a "selection bias" might have occurred.

A more bias-free evaluation using surrounding control areas and historical data shows a marginally significant 39.5% estimated rainfall increase during 1979 cloud seeding period. If the question of the East Control (extra-area effect) is concerned, evaluation using the other control areas shows marginally significant rainfall increase of 43.7% using DR and 36.6% rainfall increase using MR. In both comparisons, the probability that this is due to chance is 1 in 10.

As an evaluation technique principal component regression indicated that the 1979 Target rainfall was more unusual than do the MR or DR results indicated when all the four control areas were used. The MR (or equivalently PCR) and DR also indicated that the 1979 Target rainfall was unusually high when only three control areas were used.

5. ACKNOWLEDGMENT

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6. REFERENCES

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