A BRIEF DESCRIPTION OF AN EXPERIMENT ON ARTIFICIAL STIMULATION OF RAIN IN THE NECAXA WATERSHED, MÉXICO

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1. Introduction

Since 1949 the Mexican Light and Power Company has conducted silver iodide cloud seeding experiments in Necaxa, Puebla, México. This report is a continuation of earlier descriptions of the project [1], [2], and extends the evaluation by using the method of historical years (years before the cloud seeding was started) and applying to them the random seeding schedules used in the later years of experimentation. Further, in order to investigate possible carryover effects of seeding, the first day after seeding is studied.

The Necaxa target area and its control, about 60 miles to the ESE, are shown in figure 1. The target area of about 531 square miles has been divided into two sections for the purposes of the experiment: the upper section with an average elevation of 7500 feet and the lower with an elevation of 5300 feet.

The seeding was done by plane from 1949 to 1955, with no seeding done in 1952. Beginning in 1955, ground based generators were used instead. Seeding was done during the rainy season, June through October, and, starting with 1956, the days to be seeded were chosen at random at the beginning of the year.

2. Methods of evaluation used

In evaluating the results of cloud seeding, two main methods have been used. The first was historical regression. Using seasonal data for the fifteen years prior to the years of operation, a regression line was computed comparing rain in the Necaxa areas with that in the control zone. The correlation coefficient between the amount of rain in the upper Necaxa area and the control area was 0.97. For the lower Necaxa target and the control area the correlation coefficient was 0.95. The deviations from the regression line in the historical years were due to natural phenomena. When the data for the years of operation are added, compared to the same historical regression line, the deviations should increase systematically if the seeding is effective. This method indicates that the effect

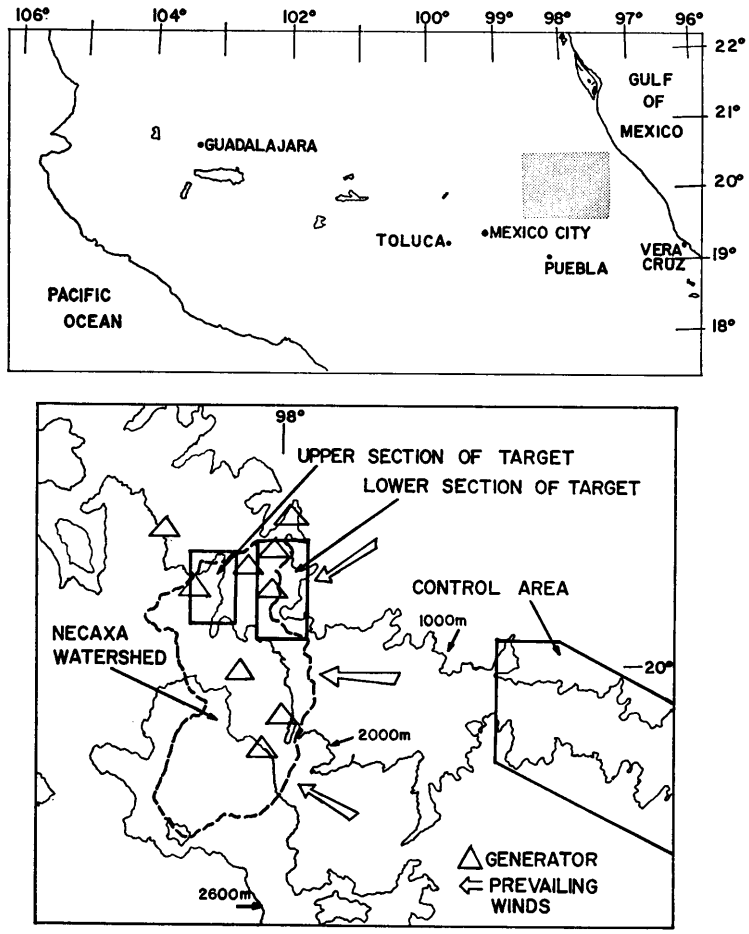

FIGURE 1

Location of target and control areas (lower panel) and location of this panel within central México (upper panel, shaded area).

of seeding was positive in the upper target; of the sixteen years of operation, eleven years show substantial increases in precipitation and only five show slight decreases in the upper target. In the lower target the results were less good, but the overall picture was one of increased precipitation during the years of operation. Some of the decreases appear to be due to torrential rains during cyclones, which have affected the control zone more than the target areas on some days.

In the upper zone of the target, cumulative departures from the historical regression line total 1671 mm increase in rain throughout the period of operations. In the lower target the gains did not start until the use of ground based

generators and the cumulative departures from the historical regression line total 999 mm.

The second method of evaluation employed separates daily precipitation amounts at the target into those for seeded days and those for unseeded days. Days in which there were rains of more than 20 mm in the control zone were excluded since there seems to be no detectable effect of cloud seeding during intense rains. This result may be due to scarcity of data or the drifting of AgI smoke into the control zone during cyclonic disturbances or easterlies.

Daily departures from the normal amounts of rain in the upper target area of Necaxa compared to those of the control zone were used. The normal for 0.1 to 4.9 mm of rain, from 5.0 to 9.9 mm and from 10.0 to 19.9 mm were obtained from the 15 years of historical data for each month, and were applied to get daily departures. These were used to construct several histograms. Table I

TABLE I

DAILY DEPARTURES WITH RESPECT TO THE NORMAL PRECIPITATION BETWEEN THE UPPER TARGET AREA AND THE CONTROL AREA

	Historical Series (15 yrs ea.)				Years of Operation			
						Unseeded Days		
	Series I	Series II	Series III	Series IV	Seeded Days (15 yrs)	(15 yrs)	9 Random Seeding Years	First Day After Each Seeded Period (15 yrs)
Number of negative cases	667	678	667	637	522	381	189	126
Number of positive cases	383	382	394	388	393	244	130	99
Total	1050	1060	1061	1025	915	625	319	225
Value (mm) of negative	2536.0	2546.5	2669.0	2663.0	1977.5	1574.0	840.5	592.5
Value (mm) of positive	2437.0	2416.0	2458.0	2605.0	2818.3	1457.0	765.0	690.5
Difference	−99.0	−130.5	−211.0	−58.0	840.8	−117.0	−75.5	98.0
Ratio of positive to negative values	0.96	0.95	0.92	0.98	1.42	0.93	0.91	1.17

summarizes the information from which the histograms were constructed. Table II gives additional historical data.

TABLE II

RATIO OF POSITIVE TO NEGATIVE VALUES FOR TEN ADDITIONAL HISTORICAL SERIES OF 15 YEARS EACH

0.97	0.92	0.99	1.05	0.90	0.99	0.92	0.91	0.91

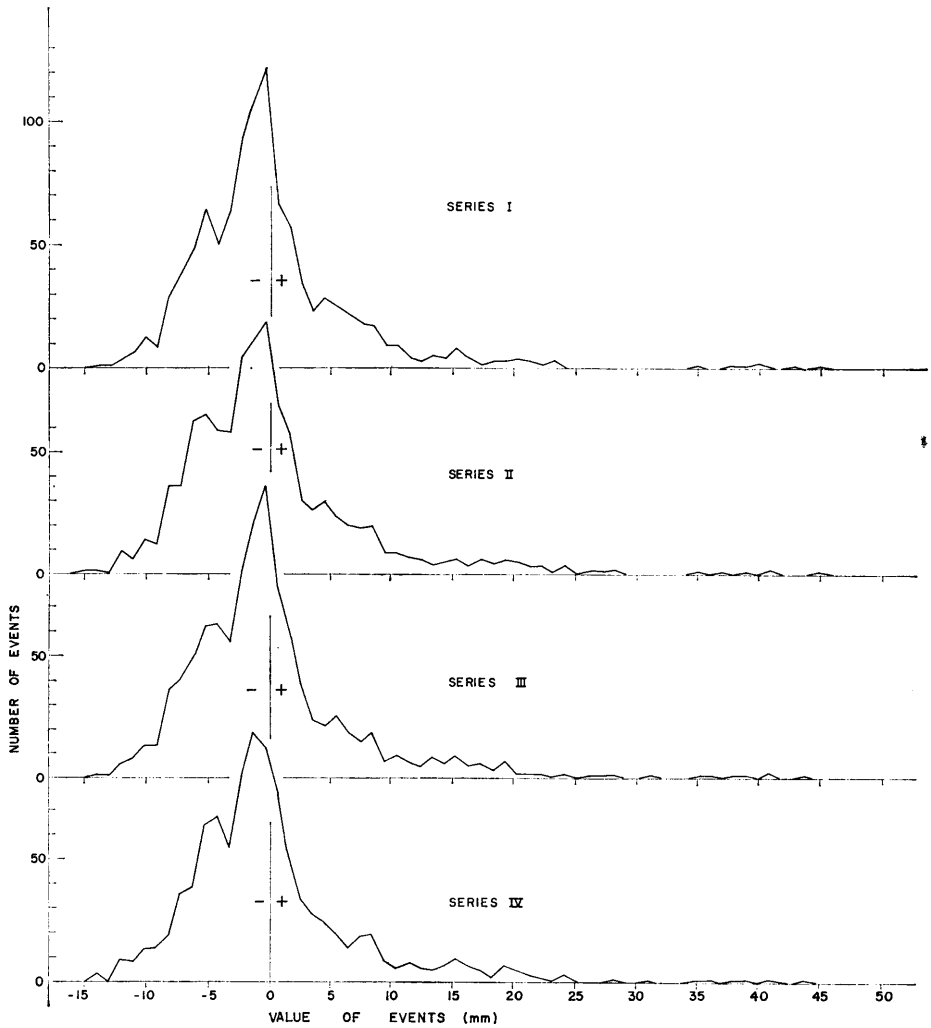

FIGURE 2

Histograms of daily departures with respect to normal rain
in the upper Necaxa target area compared to the control area.
Four 15 year series based on historical data without seeding operations.
Fictitious seeding accomplished by applying the random seeding schedules
of the years of operation, beginning with 1960 for series I,
1961 for series II, 1962 for series III, and 1963 for series IV.
Data include rains less than 20.0 mm in the control area
and the corresponding amounts for the same day in the upper target area.

As a check on the method of historical regression, fictitious seeding was studied. In figure 2 are shown four series of 15 years of fictitious seeding, each applying the random seeding schedules from actual seeding to the historical years. In all of the histograms the preponderance of negative deviations can be noted; however, the total value in millimeters of precipitation in the four historical series, as would be hoped, is very similar for positive and negative departures with an average difference of about two per cent. The histograms are all rather skew and, although there are more negative differences, the amount by which control exceeds target is small, so the total effect is near zero.

Figure 3 shows a histogram of 15 years of actual seeding, together with a histogram averaging the four fictitious seeding histograms of figure 2. The

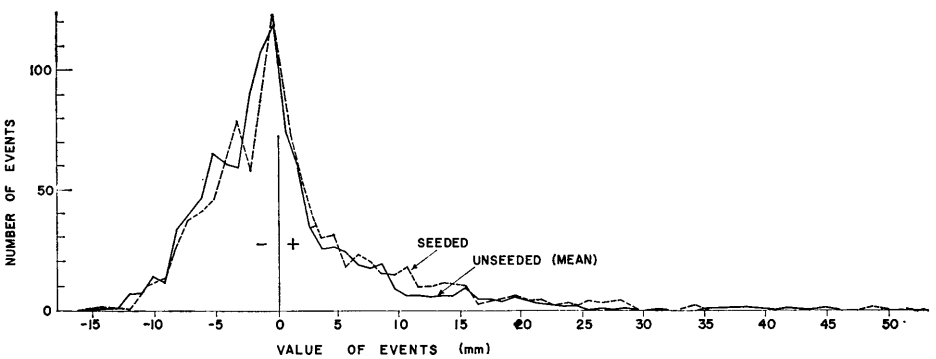

FIGURE 3

Histograms of daily departures with respect to normal rain in the upper Necaxa area compared to the control area. Broken line represents 15 years of actual seeding and the solid line shows the mean of the four historical series of figure 2. Numbers of cases in histogram of actual seeding were multiplied by 1.15 to make the two histograms comparable. Data include rains less than 20.0 mm in the control area and the corresponding amounts for the same day in the upper target area.

histogram of actual seeding is also skew, with more negative than positive cases, but since the long tail represents high positive values the net effect is positive.

In figure 4 appear two histograms of unseeded days; the upper histogram is for the full 15 years of seeding and the lower is for only the nine years 1956 through 1964 in which the days to be seeded were chosen strictly at random. In these two histograms, as in the four histograms of fictitious seeding, the total value in millimeters is about the same for negative and positive cases, even though the number of negative cases outweighs the positive.

The histogram in figure 5 studies the first day after each period of seeding.

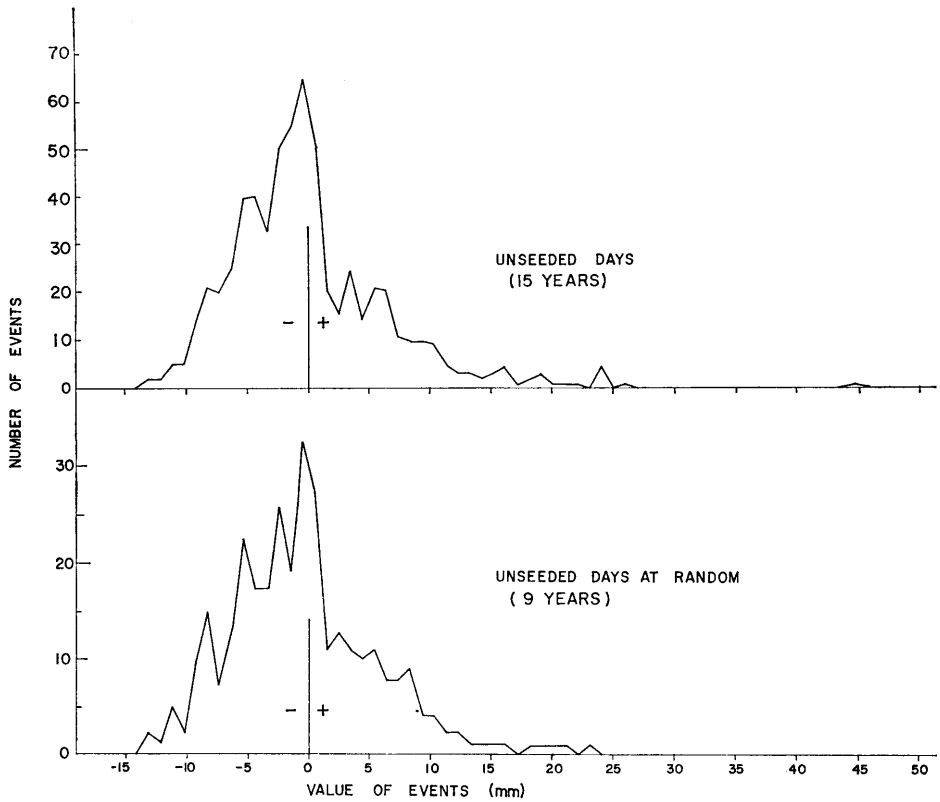

FIGURE 4

Histograms of daily departures with respect to normal rain
in the upper Necaxa area compared to the control area.
Upper panel shows departures on unseeded days during 15 years of operations.
Lower panel shows unseeded days during 9 years (1956–64)
in which seeding was done at random.
Data include rains less than 20.0 mm in the control area
and the corresponding amounts for the same day in the upper target area.

In this skewed histogram the value in millimeters is greater for the positive than for the negative values, but less strikingly so than in the histogram of seeded days.

3. Historical sequence

The rather persistent increase which is shown by regression analysis, especially in the later years, indicates a substantial gain in precipitation. This can be estimated as a year and a half of rain in the total of 15 years.

The comparison of seeded with unseeded days showed a persistent increase

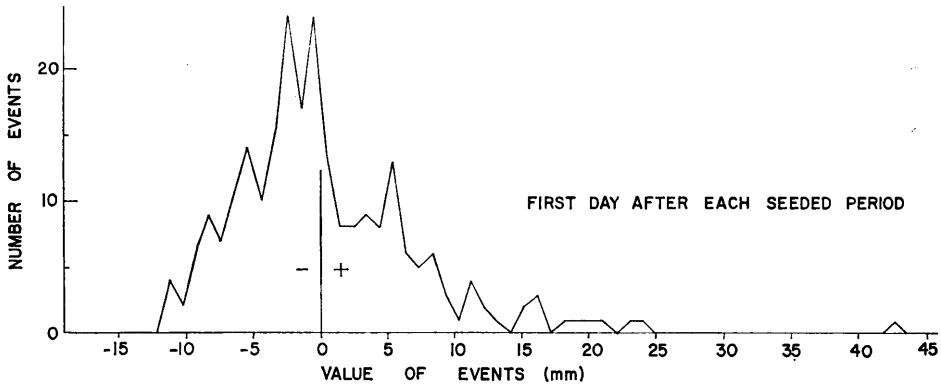

FIGURE 5

Histogram of daily departures with respect to normal rain in the upper Necaxa area compared to the control area. Shows departures on first day after seeded periods rather than during seeded periods (15 years of operations). Data include rains less than 20.0 mm in the control area and the corresponding amounts for the same day in the upper target area.

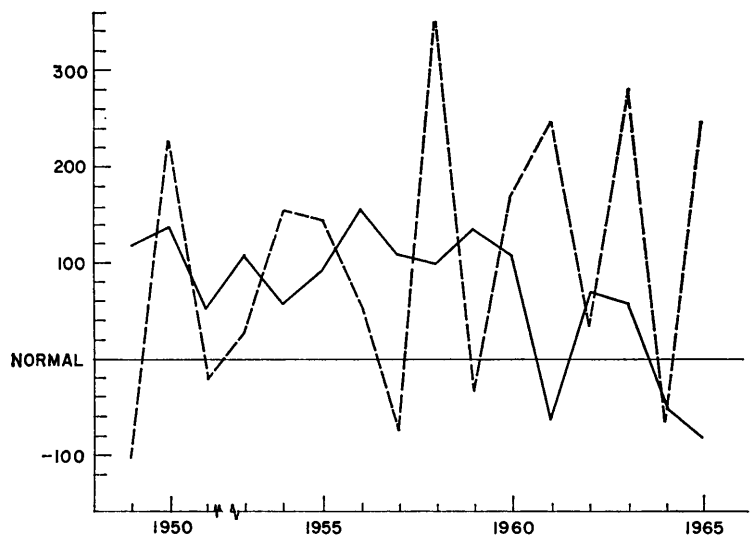

FIGURE 6

Comparison of results using historical years method of evaluation (broken line) and the daily departures method of evaluation (solid line). Upper Necaxa target area versus control area. The year 1952 is not included since no seeding was done.

until 1961, and then deteriorated in the later years and even showed slightly negative values, contrary to the results from the regression analysis. Figure 6 compares the results of the two methods of evaluation. The two methods give discordant results, but they do agree in that both methods yield many more values above the normal than below.

4. Conclusions

It is interesting that the deterioration in the results in the previous analysis occurred since the introduction of AgI generators in Honey, Tulancingo, Los Reyes, and Acaxochitlan located to the north and northwest of the watershed and which operated with the same seeding schedule assigned to the whole network.

The analysis of the unseeded day following each seeding period shows that there probably is an effect for more than one day, although less than two days, from the rain stimulation. If this phenomenon is verified, the results of the analysis of seeded versus unseeded days are impaired, since days were called unseeded which were affected by the seeding.

The preceding conclusions indicate still more the necessity for a physical investigation in order to detect any presence of AgI nuclei on the days following seeding, and in order to see if they reach the control zone during disturbed weather from cyclones or easterlies.

REFERENCES

[1] E. PÉREZ SILICEO, A. AHUMADA A., and P. A. MOSIÑO, "Twelve years of cloud seeding in the Necaxa Watershed, Mexico," *J. Appl. Meteor.*, Vol. 2 (1963), pp. 311–323.

[2] ———, "16 Años de operaciones de estimulación de lluvias en las Cuencas de Necaxa (Pue.) y Lerma (Méx.)," México, D. F., Compañía de Luz y Fuerza del Centro, S. A., 1966, pp. 1–14.