EVALUATION OF AN OKLAHOMA WEATHER MODIFICATION PROJECT

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A method termed neighborhood gradient analysis was developed to examine the variance in precipitation statistics for the area of Stillwater, Oklahoma. It is shown through use of correlation coefficients that year-to-year variation in precipitation contributes more to the variance statistic than does station-to-station variation during the same one-year intervals. Results from the 1972-73 season indicate there was not enough difference, during that one year, between the target and its surroundings to be detectable, *i.e.*, less than a 20% difference was observed between Stillwater and its neighbors.

During the spring of 1972 the water level of Lake Carl Blackwell was lower than at any time of record since its initial filling. After interviewing three weather modification operators, Irving P. Krick & Associates, Inc., a Texas corporation, was selected to seed the atmosphere with silver iodide from ground generators located at various points in the State. With Lake Carl Blackwell as the target, a total of twelve generators were located at sites surrounding Stillwater. Specific target areas were the watersheds of Lake Carl Blackwell and Lake McMurtry, but included in the target area were western Payne County and immediately adjacent parts of Noble, Logan, and Lincoln counties. It was claimed that the silver iodide generators would change the existing rainfall gradient so as to favor the target area.

The present investigation represents an attempt to evaluate the performance of the contractor. U. S. Weather Bureau raingauge data were used in this evaluation.

The actual delimitation between what was "target" area and what was not is not clear at this time. There are no known lee waves or standing waves in the Stillwater region, but the nocturnal jet stream does influence the distribution of airborne matter. Therefore, a further task of this evaluation was to try to map or otherwise determine the actual extent of effects in all directions from the area officially designated as "the Target."

Statistical problems related to weather modification in general were discussed in the Fifth Berkeley Symposium series (1). Further and more recent discussion of the statistical problems has been provided by Schickedanz and Huff (2), while Neyman et al. (3) have pointed out the time influence and geographic distribution problems in analyzing precipitation statistics from results of Arizona experiments. Results of an older study of ground-based cloud seeding in Florida by Baum et al. (4) very closely paralleled the experience in Oklahoma.

The present study deals with time increments of one year and thereby minimizes both the short-term effects and the time-related information in the results. The study, which specifically addresses the geographic-distribution effects of weather modification in the north central Oklahoma region, also minimizes orographic influence. If the Neyman-Scott findings prove to be applicable to this Oklahoma Plains region, it may become necessary to extend the neighborhood gradient method to much further distances.

NEIGHBORHOOD GRADIENT ANALYSIS

The method of neighborhood gradient analysis examines the variance in rainfall statistics from several standpoints. (a) The targeted area is regarded as being imbedded in a substantially uniform meteorological situation. For example, the *Climatic Atlas of the United States* (5) shows a band of isohyets extending from the center of Texas northward through the Great Plains to Nebraska. These isohyets are fairly regular in spacing, moderately flat in gradient, and smooth in contour over large areas. Any station within the area would be expected to show consistent and regular relationship to its surrounding neighbor station. (b) Claims of absolute rainfall change are regarded as expressions of excessive zeal. Instead, the modification of a target area is viewed as preferentially changing the gradient between the target and its surroundings during each available opportunity for modification. Weather modification should cause a percentage or relative change in a target with respect to the area outside the target and should operate continuously. (c) The Stillwater location minimizes orographic effects from hills, mountain lee waves, or large sources of water. This is directly related to item (a) above in that the regularity of rainfall gradient also indicates regularity of topography and meteorology. (d) Time domain analyses are considered only after spatial or neighborhood differences and gradients are calculated. As implied above in (a) and (b), geographic spatial differences should influence the basic data more than time variation at any one station. The advantage of this approach lies in the use of space-domain data. The question as to whether the target area benefits at the expense of the surrounding non-target area is not answered by this method. Successive or enlarged applications of this method to the surroundings can give some idea as to absolute precipitation behavior within the target area.

DATA AND ANALYSIS

Defining the neighborhood

Figure 1 shows an enlarged section of the rainfall contour map from the *Climatic Atlas of the United States* (5). The section is a 60-statute-mile-radius circle drawn with Stillwater at its center. One can see that isopleths of rainfall are quite regular in the eastern half of the area, but more irregular in the western half. Within the area, the gradient is moderate compared to that of other regions to the east and west. Radial geometry within the general area of the circle was used to analyze and define the neighborhood of Stillwater.

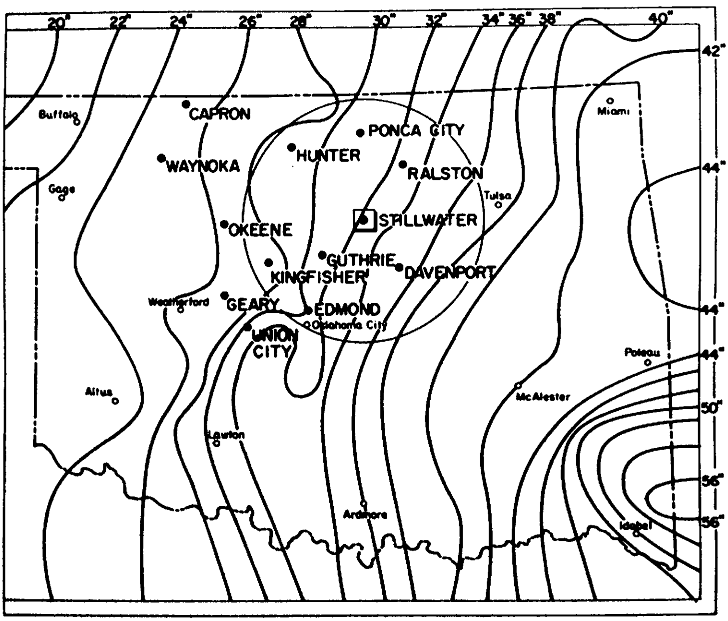

FIGURE 1. Map of north central Oklahoma showing the designated target, Lake Carl Blackwell watershed, together with 30-year average isohyets for the state.

Figure 2 contains two plots and lists stations considered in this study. The upper plot shows the smoothed mean gradient of precipitation in the neighborhood of Stillwater (the solid line) as well as the actual gradients (points) of the 20 stations with data extending from 1931 to 1960. The center plot shows the distance of each listed station from the Stillwater 2W raingauge. The 48 stations listed include all present weather service stations within approximately 60 statute miles of Stillwater. The data were plotted as shown for two reasons: first, to permit one to judge the gradient behavior of any one station with respect to its neighbors; second, to give a picture of departures from normal in various directions or locations with respect to Stillwater. The second factor is important in determining upwind, downwind, or plume behavior outside the designated target area. Data from several stations listed were not used because they were unsuitable as controls. A few stations had consistently anomalous behavior, whereas others had a nonrepresentative sample of precipitation or a faulty raingauge for one year and, therefore, were not considered for that year. This plot was useful for editing nonrepresentative data.

Expected average rainfall is seen to be greater southeastward from Stillwater (maximum gradient occurs at 130° and is a plus 0.1 inch per mile average at the 60-mile distance compared to Stillwater), as reflected in the large positive gradient of Figure 2. Expected annual rainfall is less westward from Stillwater with a more irregular gradient than toward the east.

Forming the statistics

The mean ($\bar{P}_x$) of annual precipitation at any station (x), the variance and standard deviation (σ_x^2 and σ_x, respectively) over the years of data at station x, and the correlation coefficients (R_{xy}) between stations were calculated. For the analysis, data from the years 1950 through 1971 were chosen. Data from this period have increased over data for the period going back to 1931, the initial date of the Weather Service statistical data base.

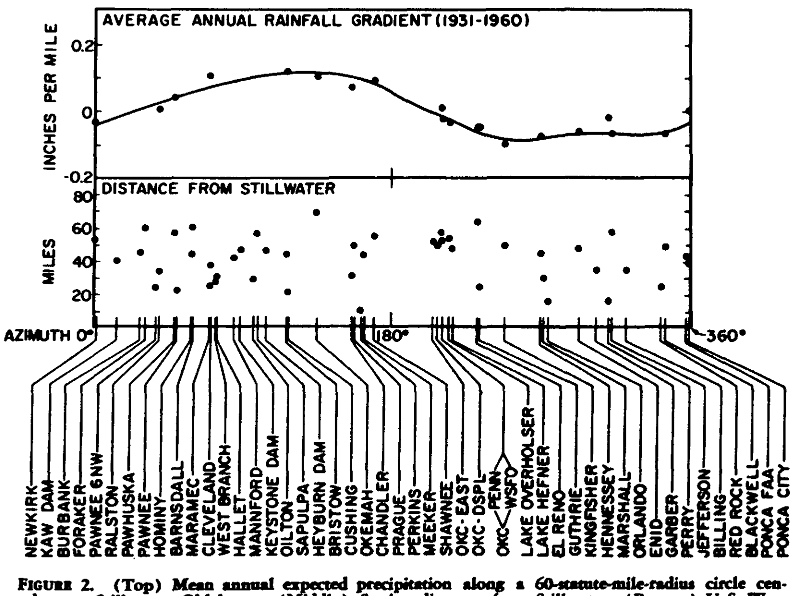

FIGURE 2. (Top) Mean annual expected precipitation along a 60-statute-mile-radius circle centered upon Stillwater, Oklahoma. (Middle) Station distances from Stillwater. (Bottom) U.S. Weather Service raingauge reporting stations plotted according to their respective azimuths from Stillwater.

In 1959 an abnormally heavy rainfall year was recorded at the Stillwater raingauge. Therefore, 1959 data for all stations were deleted. The deletion makes the data base effectively 21 years in number.

A station was not considered as acceptable in this study unless it (a) had continuous data since 1950, with no more than one year of missing data in the period 1950 through 1971, and (b) showed a gradient behavior such that the mean 21-year gradient was within one standard deviation of the nearest neighbor on each side. Using these two criteria, data from six of the 48 possible stations in the defined neighborhood were deleted. Data from Pawnee 6 NW, Oilton, Orlando, and Kaw Dam were deleted by the first criterion. Data from the Perkins and Hallett stations failed by the second criterion, as illustrated in Figure 3. Data from the remaining 42 stations were used.

Figure 3 shows the newly formed and smoothed gradient profile similar to that of Figure 2 except that of Figure 3 was derived from the data base of years 1950 through 1971, excluding 1959.

Figure 4 shows a correlation coefficient map for the neighborhood of Stillwater, based on the years 1950 through 1971, but excluding 1959. Each year's gradient was taken individually, i.e., not averaged for the calculations. The correlation coefficients calculated for use in Figure 4 are functions of two variables, space and time:

$R_{x,swo}(d,t)$ where d = distance between the two stations. Thus, from a definition of the correlation coefficient, it is required that the covariance, $\sigma_{x.swo}$, be also a function of both space and time.

$$\sigma_{x,swo}(d,t) = R_{x,swo}(d,t) * \sigma_x(t) * \sigma_{swo}(t)$$

The measured precipitation at each station can be influenced by two factors. The first can be viewed as a "common mode" factor, i.e., if it is raining in the neighborhood all neighborhood gauges will probably measure some precipitation. Data stratification into frontal and air-mass situations, which show different degrees of coherence, would help define "probably." The

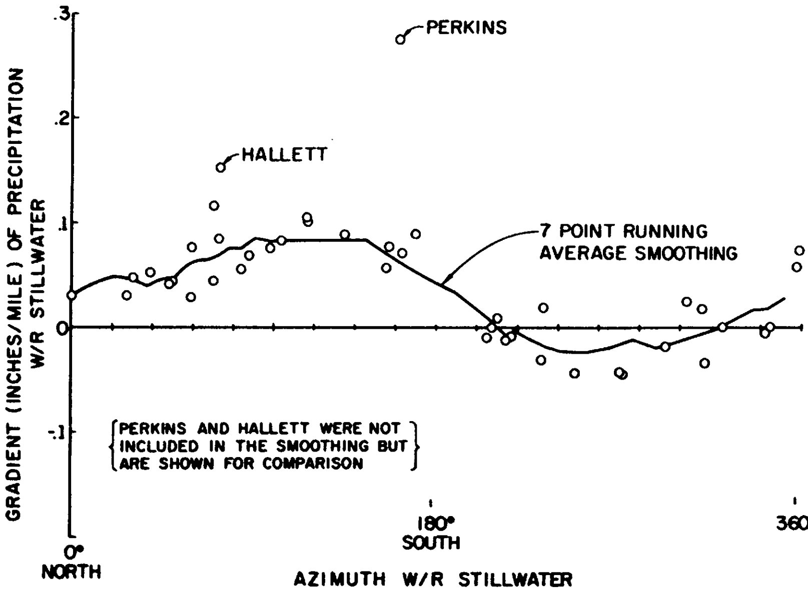

FIGURE 3. Plot of neighborhood gradient profile based upon data from years 1950 through 1971.

second factor is a random sampling factor which depends upon the sampler (gauge) location, each cloud's own precipitation distributions, and other such largely unknown factors.

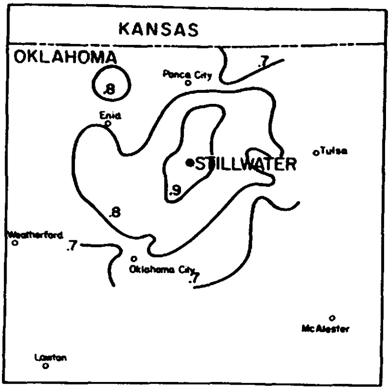

FIGURE 4. Annual precipitation correlation coefficient map for the neighborhood of Stillwater, Oklahoma.

The strong (≥.7) correlation coefficients in the neighborhood of Stillwater suggest that up to one-half the "common mode noise" in precipitation statistics can be cancelled or minimized by differencing the data between stations. The map in Figure 4 suggests there is an elliptical symmetry to this "common mode noise" effect.

After performing this differencing on the statistics, it was of interest to see whether there remained a distance effect or whether time variations in the precipitation were important. Thus $\Delta P_{x.swo}$ was formed for the difference in precipitation between station x and Stillwater for each station and for each year, 1950 through 1971, excluding 1959. A variance and a standard deviation were calculated for each of the 42 sets of station differences using the 21 years of precipitation difference for that set.

One would expect that the resulting variance would increase as a function of increasing distance from Stillwater. The plot of regression of standard deviation in $\Delta P_{x.swo}$ against radial distance from Stillwater (Fig. 5) shows, however, that the change in distance accounts for only a minor contribution (about 18%) to the total variance of precipitation difference. The implication is that the time, i.e., the year-to-year variance in precipitation, accounts for a much larger contribution to total variance than does distance change. The smallest correlation coefficient in this area is .7, an indication that not less than 50% of the

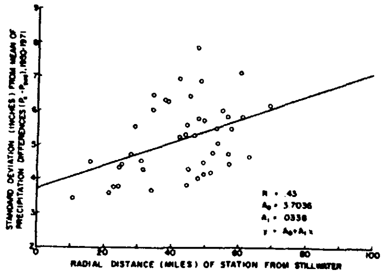

FIGURE 5. Linear regression of variance in precipitation difference versus radial distance from Stillwater for 44 stations in the neighborhood of Stillwater.

"noise" in the data is "common mode noise," common mode variance in the precipitation. Of the remainder, time variance contributes most to the variance behavior.

This result indicates that comparison of differences in precipitation between stations over a given yearly interval will result in substantially lower variances than will comparison of year-to-year precipitation at any one or several locations.

Following this result, one concludes that differential precipitation analysis should be used as a test parameter, and differences in precipitation between stations should be formed as the basic data set upon which to form variances and perform other statistical tests for weather modification. This is true especially when one wishes to observe spatial changes, e.g., between "target" and "non-target" areas. The behavior difference between "target" and "non-target" areas should then emerge (or fail to emerge for null results) as a relatively strong correlation among otherwise weakly correlated events.

Gradient analysis applied

Since the stations in the defined neighborhood of Stillwater are not separated by a uniform distance, but are distributed in approximately a Gaussian manner, radially in distance with respect to Stillwater, it was necessary to form the gradient of precipitation rather than precipitation difference for each station-pair. Use of precipitation gradient allowed comparisons among stations and in various directions and distances from Stillwater throughout the whole area of the neighborhood, not just at specified radii from Stillwater.

Figure 6 shows smoothed precipitation gradients for the 22-year period together with the ± 1σ (one standard deviation) of the gradient over the 21 data years taken one year at a time (solid line), average using two years at a time (dashed lines), and averaged three years at a time (dotted lines), i.e., basic one-year gradients were averaged over two years and again over three years to yield running mean gradients. Variances to those running mean gradients are shown in Figure 6 as the "2 year mean" standard deviations and the "3 year mean" standard deviations, respectively.

Given homogeneous (ergodic) data over all stations, one would expect the curves of Figures 6 and 7 to behave as $\sigma \alpha 1/N$, where N is the number of years of data. While that is true for an ensemble of data from all stations, it is less true for individual stations. In this case the smoothed mean gradient is nonzero and nonconstant from one station to the next, even for stations adjacent to each other; hence, it is misleading to compare directly one station's variance behavior with another's behavior without first normalizing the data. Cyclic or harmonic behavior in time in the data also may be important. Therefore, the averaging process, which is a form of spectral filtering, may suppress or accentuate the effect depending upon the number of years averaged. This fact should, perhaps, be investigated further.

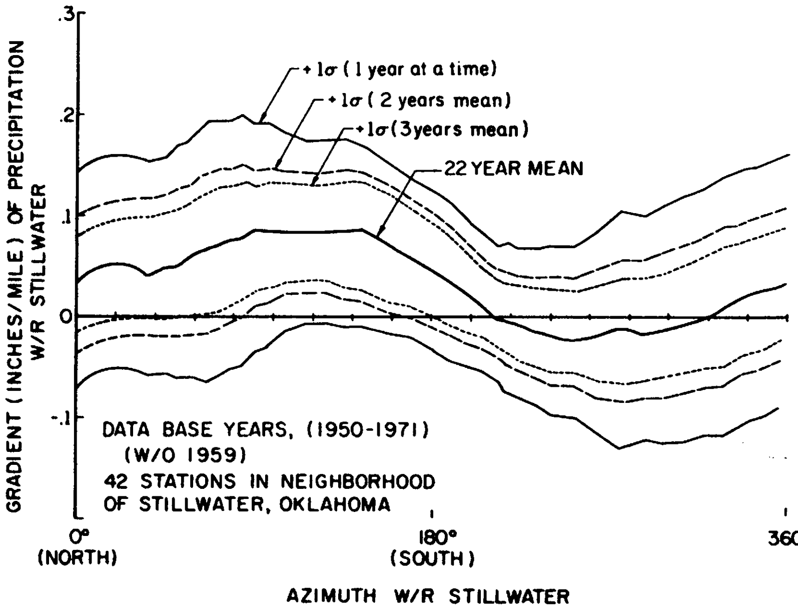

FIGURE 6. Smoothed 22-year precipitation gradients with respect to Stillwater and showing ± 1σ (one standard deviations) to the mean gradient.

Figure 7 presents a typical precipitation-gradient variance behavior in the defined neighborhood as a function of years of data available. Also shown on the graph is a simulated change in the "target" (Stillwater) rainfall. The target's change is assumed to be a fixed percentage and uniform over the number of years shown.

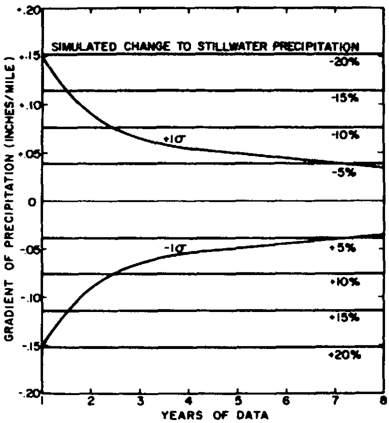

FIGURE 7. Typical behavior of the variance in mean gradient of precipitation as a function of number of years of data averaged and superimposed upon a simulated change in mean rainfall at Stillwater.

The purpose of Figure 7 is to illustrate the number of years of data necessary to observe a given percentage change in the target's rainfall with respect to another (control) station. Thus, for example, to observe change of ± 10% at a level greater than ± 1σ takes no fewer than three years of data. A consistent change of ± 5% in the Stillwater rainfall would take upwards of seven years to detect at a significance of ± 1σ.

Assessing overall confidence levels and significance of results now involves deciding on how many observations need to be made. Since the correlations coefficient map (Fig. 4) indicates strong correlations in precipitation between Stillwater and all other stations in the neighborhood, it is presumed that the same type of correlations exist among all stations. Therefore, no set of data is clearly independent of any other set of data.

Results of the 1972-73 program

Seeding activities of the Stillwater Project commenced on May 15, 1972 and terminated May 14, 1973. However, there was a period in excess of a month in the Spring of 1973 when seeding was not performed. Seeding was stopped on March 23, 1973, performed on April 14 and 15, 1973, and then stopped again until May 15, 1973. For the purposes of this evaluation, the project year is considered to be May 1, 1972, through April 30, 1973.

Figure 8 presents the one year gradients of precipitation with respect to Stillwater raingauge plotted against the 22-year mean gradient, ± one standard deviation of gradient. The figure shows that well over 2/3 of the gradients lie within one standard deviation of the mean gradient, thereby indicating that the 1972-73 data appear to be within normal expectations. By referring to Figure 8, it can be said that the weather modification at Stillwater did not change Stillwater's precipitation more than plus or minus 20% (6.5″) from its neighbors.

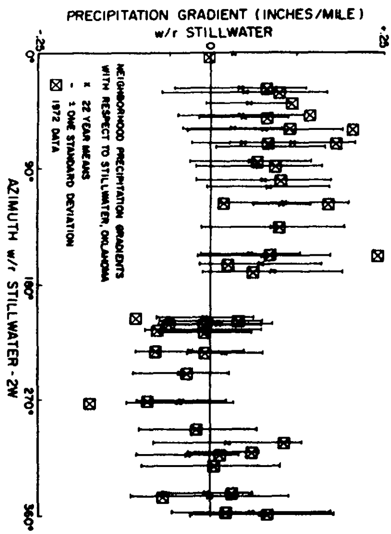

FIGURE 8. Neighborhood precipitation gradients from the 1972-73 project season compared to the normally expected gradient behavior.

One additional year of data will be necessary to make a statement (within one standard deviation confidence) about a 15% or more change. Figure 8 does show that the group of stations in the northeast quadrant around Stillwater all appeared to have a slightly more positive gradient than normal.

It is not possible to attach a significance to this since all the gradients are well within normal bounds. However, one may speculate that the seeding was beneficial not to Stillwater, but downwind of Stillwater, i.e., stations north and east of the target. Again, more data will be necessary before one can attribute the cause to seeding or to naturally occurring events. There are years of record when certain regions surrounding Stillwater show abnormally high and abnormally low gradients as a natural occurrence.

CONCLUSION

Results of applying the neighborhood gradient technique of analysis to the Stillwater weather modification project show that the precipitation pattern for Stillwater during 1972-1973 was not significantly changed from the normal precipitation pattern.

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