THE AREA OF MAXIMUM EFFECT RESULTING FROM THE LAKE ALMANOR RANDOMIZED CLOUD SEEDING EXPERIMENT 1/

By

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Introduction

The Pacific Gas and Electric Company has been engaged in cloud seeding since 1953. The evaluation of the early experiments, however, was characterized by unresolvable ambiguities. For example, on one watershed the streamflow analysis indicated a positive effect while the precipitation analysis on the same watershed showed a small negative effect.

In order to resolve these ambiguities, the Company decided in 1960 to conduct a randomized experiment. This experiment was set up on the Lake Almanor watershed during 1960-1962. Five years of testing have been completed, and some of the results are presented in this report.

Site Description

The Lake Almanor watershed is located in the northern Sierra Nevada Mountains of California, and encompasses approximately 500 square miles, Figure 1. It extends 25 miles east-west and 20 miles north-south. Lake Almanor is located in the southern portion of the watershed, and has an area of approximately 45 square miles. The elevation of the watershed ranges from 4,500 feet at the lake level to 10,467 feet at Mt. Lassen; however, most of the watershed lies below 7,500 feet. The area of the watershed used in the experiment lies below 6,500 feet, and covers approximately 300 square miles, extending 20 miles east-west and 15 miles north-south.

There are several good roads in this area which provide reasonably good access to many of the precipitation gages. However, the high elevation gages and the burner sites can be reached only by use of snow vehicles during most of the winter season.

During the wet season, November to May, there is a high frequency of storms in this area. At Chester, located in the central portion of the watershed, the annual precipitation averages 31.42 inches, and ranges from a maximum of 51.56 inches to a minimum of 16.44 inches. The annual average snowfall is 146.4 inches, and accounts for approximately one-half of the annual precipitation even at the 4,500 foot elevation. Since the main ridge of the Sierra Nevada Mountains is located west and southwest of this test area, the wind flow associated with this precipitation traverses terrain which slopes slightly downward toward the test area.

Instrumentation

Six silver iodide burners were installed on ridges or peaks within the watershed at elevations between 6,000 and 7,500 feet. Each burner site included a burner, its control system, two 500 gallon tanks of propane, a radio receiver, a radio tower, a battery pack power supply and an instrument shelter. The burners were completely automated, and were controlled by personnel at the Caribou Powerhouse 5 to 10 miles away. A 4% solution of silver iodide in acetone was burned at a rate sufficient to produce 25 grams of silver iodide per hour. Both the burners and the control systems proved very reliable.

Continuous precipitation measurements were recorded by U. S. Weather Bureau weighing type gages at 49 locations, for an average network density of one gage for every six square miles of target and control area. An ethylene glycol solution was used to protect the gage catch from freezing, and a light oil reduced the evaporation. To prevent the snow

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from sticking or capping, each gage orifice was heated with a small propane flame. This heating of the gage orifice caused a slight reduction in the measured precipitation, but the test results were not affected, since both the seeded and the unseeded gages were equally influenced.

The burners and the precipitation gage heaters were designed and fabricated by the Company, and a detailed description of them is contained in a recent paper by Hunsaker and Scott (1).

Temperature measurements were made at two locations, Prattville radar site, 5,000 feet MSL, and Mt. Dyer, 7,500 feet MSL. Temperature soundings were made during the last three years of the experiment at the Prattville location; however, there were many breaks in the record.

Wind measurements were also made at Prattville and Mt. Dyer. An internally heated wind vane at the 7,500 foot location provided some good data, but the record was fragmentary due to the severe icing conditions experienced at this site. Continuous good quality records were obtained at the 5,000 foot location, but these data were of limited value, because wind observations at ground level are not a reliable basis for estimating the wind direction at higher levels.

Radar scope pictures of precipitation cells and tracks of balloon releases were also made at the Prattville location during the seasons 1964 to 1967. The quality of these data was high, but again there were breaks in the record.

Experimental Design

The cloud seeding burners were placed south and southwest of the target area, because southerly or southwesterly flow was expected to be associated with most of the precipitation. The release of the silver iodide from high peaks or ridges, approximately 1,000 feet above the target area, increased the likelihood of the silver iodide reaching the cloud layers which were colder than minus five degrees centigrade, the threshold of its effective range, Fletcher (2). In fact, during some cold storms, the silver iodide was released directly into this layer of the cloud, and therefore was immediately effective.

The total target area was divided into two approximately equal parts, east and west, Figure 2. Initially, it was planned that one of these sub-targets would be seeded during every seeding period. The burners which would seed the two target areas were designated the west burner group and the east burner group. Thus under southerly flow, the two burners in the east group would seed the east target area, and the four burners in the west group would seed the west target area.

During each seeding operation, one of these burner groups was selected according to a set of random decisions made up before the season began. When the forecaster and field meteorologist decided that the weather conditions were favorable for seeding, a sealed order was opened to determine which burner group would be operated. This information plus the starting time of the operation was then transmitted by the forecaster to personnel at the Caribou Powerhouse who handled the actual ignition of the burners. If favorable conditions persisted, another sealed order was opened, and the designated burner group was operated. A seeding period consisted of 11 hours of burner operation followed by a one hour pause to allow the material time to move out of the area.

The procedure described above was based on the assumption of southerly or southwesterly flow, and it was not until the seeding period had passed that the actual wind flow was known. To utilize the available data when the wind flow had actually been westerly, the area seeded by the west burners during westerly flow was designated as the target area, Figure 3. This particular target area was defined such that none of its gages were seeded when the east burner group was operated. Another group of gages located in the extreme western portion of the area was never seeded during westerly flow, and they were designated westerly control gages. Thus it was possible to use the data generated during westerly flow, even though the randomization procedure used to select the burner group was based on the assumption of southerly flow.

In summary, when the wind direction was southerly, the double seeding or crossover test was used; i.e., one of the two targets was seeded during every operation. When the wind direction was westerly, the target area was seeded during approximately one-half of the seeding periods, and the control area gages were never seeded.

For the experimental unit, a twelve hour period was chosen. Although a shorter period would have increased the sample size, it would also have decreased the correlation between target and control. These two factors opposed each other in such a manner as to produce an optimum solution at twelve hours, Eberly and Robinson (3).

Data Reduction

During each of the five test years, 1962-1967, continuous recordings of precipitation, wind and temperature were collected from approximately November through May. The wind and temperature data were reduced as hourly averages. The precipitation data were reduced as hourly totals and recorded on punch cards.

The temperature soundings and winds aloft measurements made during seeding periods were reduced as one minute averages.

The photographs of the radar echoes of precipitation cells were examined, and the direction of movement was logged.

As a supplement to this on-site wind and temperature data, the direction of mean flow and the height of the -5 degree centigrade temperature over Northern California were estimated from upper air charts and radiosonde data.

Data Analysis

The hourly averages of the temperature data were averaged over each 12 hour seeded period and used as one classification indicator. Each seeded period was classified according to the height of the -5 degree centigrade temperature. The seeding period was classified as cold if the height of -5 degrees centigrade temperature was 7,500 feet or less, and classified as warm if the height of the -5 degree centigrade isotherm was greater than 7,500 feet. The hourly averages of the wind direction data were also averaged over each 12 hour seeded period, and the periods were classified to the nearest unit of the 16 point wind scale. If the wind direction was between west southwest and west northwest, the period was classified as westerly; when the wind direction was between south southeast and south southwest, the period was classified as southerly. Seeding periods with other wind directions or wind direction shifts were omitted from the analysis. Thus four categories of seeding periods were analyzed, cold-southerly, cold-westerly, warm-southerly, and warm-westerly.

The precipitation gages were grouped according to location with respect to the burners. The precipitation measured at each gage was totalled for each 12 hour seeding period, and these totals were then averaged over the number of gages in each target or control area. Equal weighting was applied to each gage, since they were evenly distributed throughout their respective areas.

Within each of the four categories analyzed, a comparison was made between the average target precipitation with seeding and the same without seeding. In making these comparisons two statistical methods were utilized, regression analysis and covariance analysis. Both require a control area, left unseeded, in order to perform the analysis, and make a valid comparison.

Results

After each seeded period for the five test years had been classified as previously described, there were only ten cases in the warm-westerly category. These cases were not analyzed because of the small sample size.

For the 78 seeded periods classified as cold-southerly, the east target was seeded 38 times, and the west target had been seeded on 40 occasions. The comparisons indicated a small negative effect of approximately 3%; however, the level of significance indicated that this was a chance occurrence.

The analysis of the warm-southerly category storms for the five year period has not been completed. However, the data from the first three years, previously analyzed by Eberly and Robinson (4), indicated no significant effect. Furthermore, there is no theoretical basis to expect more from the warm-southerlies than the cold-southerlies, and the analysis of the latter, as already indicated, showed a small negative effect.

In the cold-westerly storm category, the target area was seeded 30 times, and not seeded on 36 occasions. Analysis of these storms indicated a substantial increase, 32% by the regression method and 32% by the covariance method. Both results were significant at the 5% level.

In this category, cold-westerly, a more detailed analysis was undertaken to determine the distance from the burners to the area of maximum effect. The distance from the burners to the 28 gages used in this target area ranged from 1.5 to 21 miles. These gages were grouped in three different ways. The first grouping consisted of all 28 gages; the second grouping was three seven-mile distances, and the third grouping was roughly four five-mile distances, (0-5 miles, 5.1 - 11 miles, 11.1 to 15 miles and 15.1 to 21 miles).

The results of each of these groupings are displayed in Figure 4. In the total area grouping, the average increase over the 21 mile distance was 37% The percentage change in the three area grouping was approximately 37% to 40% in areas one and two and decreased to approximately 34% in area three (14-21 miles downwind). In the third grouping of four distances, roughly five mile increments, the percentage increase ranged from 32% in area one to 33% in areas three and four with a peak increase of 57% in area two, 5.1 to 11 miles downwind. All of these results were significant at the 5% level for both methods of analysis, except areas three and four of the four area grouping. In these two areas the covariance analysis was significant at the 10% level.

The percentage changes indicated in Figure 4 are plotted at the midpoint of the respective areas and are a result of the covariance analysis.

Discussion of Results

The positive effects found in the cold-westerly category are in general agreement with the fact that silver iodide seeding stimulates only the ice-crystal mechanism of the natural precipitation processes, and has no effect on the warm temperature coalescence mechanism, Fletcher (2) and Mason (5). Furthermore, the maximum effect found between 5 and 11 miles downwind is in agreement with the cloud physics. For example, if a silver iodide particle were introduced directly into the -5 degree centigrade or colder region of a cloud, the total elapsed time required for it to grow to a snowflake large enough to fall to the ground is on the order of 550 to 930 seconds. If an average wind speed of 10 - 30 MPH is assumed, this elapsed time is equivalent to between 2.0 and 9.2 miles downwind from the burners.

The elapsed time of 550 to 930 seconds was based on 120-500 seconds for growth, the 50 centimeter per second fall rate of powder snow, Mason (5), and the average difference in elevation between the burners and precipitation gages, 1,000 feet.

However, this theory does not explain the lack of results observed for the cold-southerly category. In this case, there may have been some contamination between the two target areas. For example, they are close together, and wind flow in mountainous regions is often complex. If the silver iodide plume meandered from one target to the other, then both areas would be seeded and a no-effect result would be automatic. On the other hand, the result may be real, and without a current explanation.

The lack of results for warm-southerly storms was not totally unexpected since the silver iodide treatment has no effect on the warm precipitation mechanism, and this mechanism most likely dominated during this storm type.

Acknowledgments

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LAKE ALMANOR CLOUD SEEDING EXPERIMENT
INSTRUMENTATION LOCATIONS

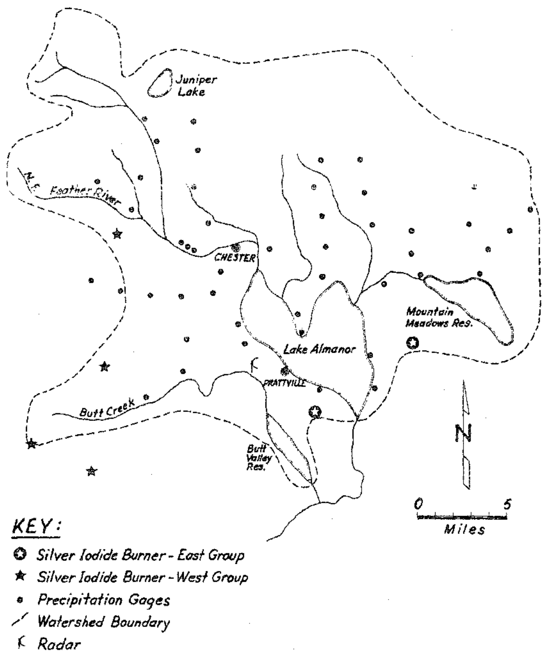

FIGURE 1

LAKE ALMANOR CLOUD SEEDING EXPERIMENT
TARGET AREAS, SOUTHERLY WINDS

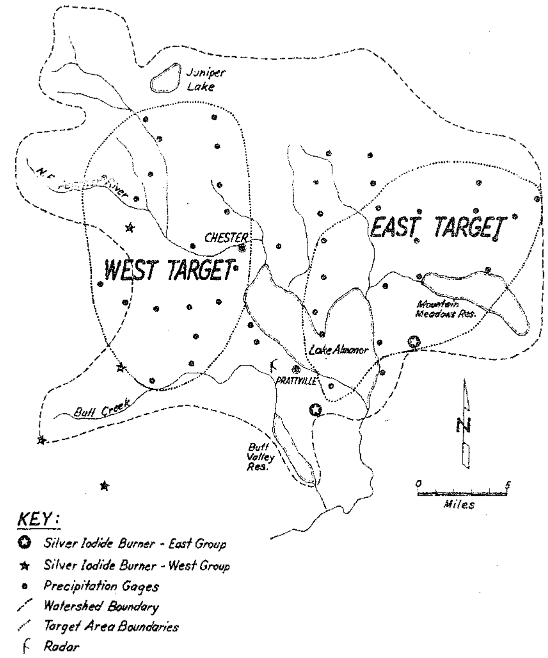

FIGURE 2

LAKE ALMANOR CLOUD SEEDING EXPERIMENT
TARGET AND CONTROL AREAS, WESTERLY WINDS

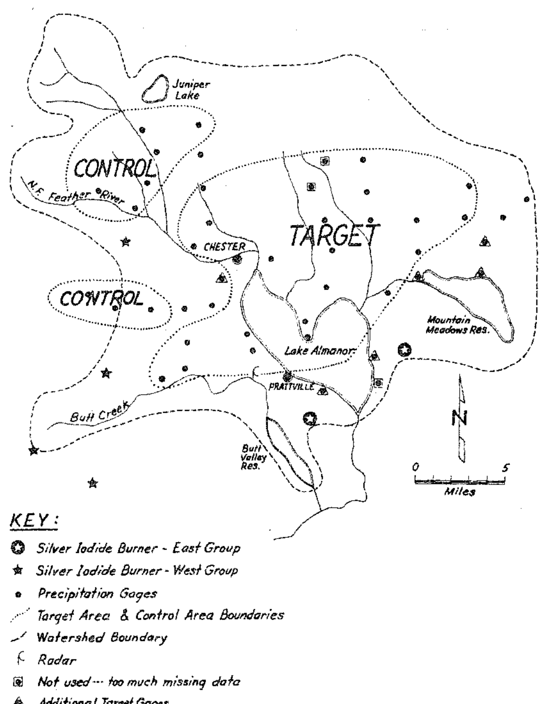

FIGURE 3

EFFECT OF SEEDING vs DISTANCE

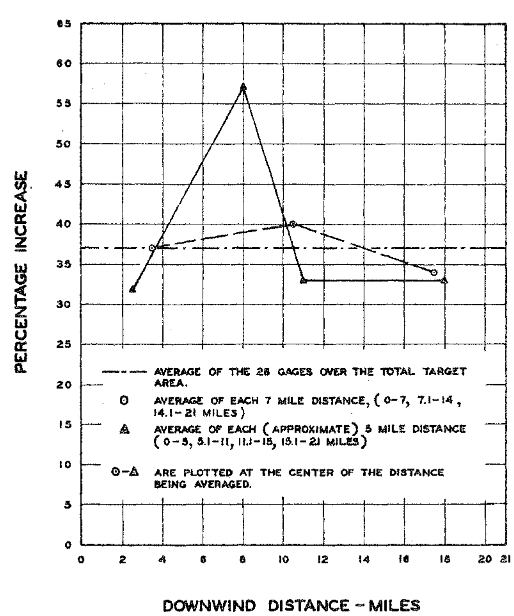

FIGURE 4

in the early stages of burner development, and also made an analysis of the burner output. The radio control system was developed by the Communications Department. The original test design, project operations, data collection, reduction, processing and analysis represent the joint efforts of the Meteorological Office Staff headed by F. J. Parsons and later by L. M. Hunsaker. Warren Scott served as the field Meteorologist throughout the test period. Special thanks are expressed to L. H. Robinson* for his many helpful suggestions in processing and analyzing the data.

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