ANALYSIS OF DATA ON HAILFALLS AS BACKGROUND FOR THE DESIGN OF AN EXPERIMENT IN HAIL MODIFICATION

Richard A. Schleusener

and

John D. Marwitz

Colorado State University

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INTRODUCTION

Development of techniques for cloud modification by cloud seeding has led to a variety of attempts at weather modification, including precipitation increase, hurricane modification, fog dispersal, and hail suppression. The natural variability of meteorological parameters is such that detection of any small change which might have been effected artificially is difficult. This difficulty is increased with the variability of the meteorological parameter being considered, and leads to frustration for cases in which high variance and low frequencies of occurrence combine to require excessive periods of time to draw valid conclusions concerning the effects of modification attempts.

These difficulties are further compounded for evaluation of attempts of hail suppression because of a lack of basic data on the nature and characteristics of hailfalls. For example, the only statistic concerning hailfalls which is readily available is "days with hail." While this parameter may serve to delimit regional differences in the average annual frequency of hail, it leaves much to be desired as a statistic which would be appropriate for detecting changes in hailfalls which might have been produced artificially.

This paper presents the results of an analysis of data on hailfalls for three seasons (1960-1962) from the hail network operated in northeastern Colorado by Colorado State University. Examination of these data provides an insight into some of the physical properties of the High Plains hailstorm, provides some of the background information required for the design of a hail modification experiment, and points out the problems inherent in a statistical analysis of a hail modification experiment.

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DATA AND METHODS

From information on hailfalls obtained from the Colorado State University network (see references 1, 2, 3 and 4 for area covered, equipment and techniques) the following data were derived and prepared for computer analysis:

From cooperative observers:

Estimated impact energy, ft-lb per ft^2	E_c
Duration of hailfall, minutes	D*
Most common stone size (coded)	MC
Maximum stone size (coded)	MX

From the passive hail indicators:

Impact energy, ft-lb per ft^2	E_i
Number of stones per square inch for (coded) diameters of hailstones	
1 - 6	N_{1-6}
2 - 6	N_{2-6}
3 - 6	N_{3-6}
4 - 6	N_{4-6}

These hail parameters were analyzed from the viewpoint of attempting to identify parameters which, on the basis of physical reasoning, might be changed if cloud seeding were effective in modification of hail. After such identification, their statistical properties were examined to determine their suitability for use in evaluation of hail modification tests, and to infer certain properties of hailstorms. Finally, certain scale changes of the hail parameters were assumed, and their statistical properties were used to estimate the number of data samples required to draw valid conclusions of the effectiveness of hail modification attempts.

TRANSFORMATIONS OF BASIC DATA

Transformations were applied to the basic data, to attempt to produce a minimum absolute dispersion of the individual coefficients of variation about

*D was removed from further analysis because of excessive bias. Most cooperators reported D in 5 to 10 minute increments.

the mean coefficient of variation $\left(\Sigma\left|Cv_i - \overline{Cv}\right|\right)$ with a physically reasonable transformation. In addition to the basic observations, X , consideration was given to each of the following transformations which were applied to each of the observations:

$$\ln X, \sqrt{X}, \sqrt[3]{X} \text{ and } 1/X .$$

The selected transformations were $\ln X$ for E_c and E_i and $\sqrt{X}$ for D, MC, MX, N_{1-6}, N_{2-6}, N_{3-6}, and N_{4-6}. The value of the mean, standard deviation, and the number of samples were determined for each transformed hail parameter set plus subsets by years, months and geographic locations. The transformations decreased the variance of the parameters considerably but the coefficient of variation continued to be greater than 1 in most cases.

TESTS OF HOMOGENEITY OF DATA

Analyses of variance were performed to determine whether or not homogeneity of data existed for the transformed variables, considering the following classifications:

- Between years for a particular month,
- Between years of all months,
- Between months of a particular year,
- Between months of all years,
- Between east and west portions of the network, and
- Between north and south portions of the network.

From these analyses it was determined that the hypothesis of homogeneity between years and between months for $\sqrt{MC}$, $\sqrt{N_{1-6}}$, and $\sqrt{N_{2-6}}$ must be rejected. On this basis and since $\sqrt{MX}$ had even more variance, the parameters $\sqrt{MC}$, $\sqrt{MX}$ and $\sqrt{N_{2-6}}$ were rejected from further analysis. The hypothesis of homogeneity between years for $\ln E_i$ when using data from all of the hail network was rejected whereas when using only data from the west half of the network it could not be rejected. The hypothesis of homogeneity between years and months for $\ln E_c$, $\sqrt{N_{3-6}}$, and $\sqrt{N_{4-6}}$ could not be rejected. The parameters $\sqrt{N_{3-6}}$ and $\sqrt{N_{4-6}}$ were rejected from further analysis due to low frequencies of occurrence.

The remaining sets of parameters, consisting of $\sqrt{N_{1-6}}$ (retained for analysis despite homogeneity considerations noted above), $\ln E_i$, and $\ln E_c$, were arbitrarily divided into subsets from east to west and subsets from north to south. The hypothesis of homogeneity could not be rejected; consequently it was decided to add a 60 mile north-south line of indicators through the west half of the network for the 1963 season.

EFFECT OF SIZE OF SAMPLING AREA ON VARIABILITY OF PARAMETERS

The coefficient of variation was computed as a function of sampling area for the 3 remaining hail parameters. From these computations it was determined that the variance of the hail parameters would be changed very little if only half of the sampling area were used. For some of the hail parameters, a reduction in sampling area produced a decrease in variance. From these results and the results of the homogeneity tests on $\ln E_i$ it was concluded that the size of the sampling area could be reduced, and half of the indicator network was abandoned prior to the beginning of the 1963 season.

TESTS FOR NORMALITY OF PARAMETERS

The $\ln E_i$ and $\ln E_c$ data sets and subsets by years, were tested for normality. In nearly all sets and subsets the data were highly skewed left, with the kurtosis ranging from leptokurtic to isokurtic to platykurtic.

TESTS FOR INDEPENDENCE OF OBSERVATIONS

Correlation coefficients were computed between certain combinations of the hail parameters averaged over one region vs the parameters averaged over other regions approximately 25 miles away. The results indicate no significant correlation.

Correlation coefficients were also computed between the hail parameters $\ln E_i$ and $\sqrt{N_{1-6}}$ for each dented indicator with the mean of its neighbor (and neighbors) located approximately 2 and 4 miles away. Although the correlation coefficients were all less than 0.50, the hypothesis of dependence could not be rejected.

TESTS TO ESTIMATE THE PERIOD OF TIME REQUIRED TO DETECT SCALE CHANGES IN THE HAIL PARAMETERS

Computations were made to estimate the period of time required to obtain significant differences in the hail parameters, assuming various scale changes in the parameters. These computations assume that negative reports of hail occurrence can be obtained in those cases in which complete hail suppression might be attained, that all hail-producing storms would have been subjected to a modification treatment during the period of 15 May to 31 July, and that the average number of hail samples will remain constant. It may be noted that "success" in a hail modification experiment would increase difficulty of statistical analysis because of an increase in zero values.

When these three (questionable) assumptions are made, a period of 3 to 5 years is estimated to detect scale changes on the order of 10 to 25 percent in the hail parameters.

CONCLUSIONS

1. From the 9 hailfall parameters collected by the Colorado State University hail network, 6 were eliminated for use in any statistical analysis of hail modification because of bias, non-homogeneity between years, or sparcity of samples. The remaining parameters were E_c , E_i , and N_{1-6} .
2. The transformations which produce the minimum $\Sigma\left|Cv_i - \overline{Cv}\right|$ are $\ln E_c$, $\ln E_i$, and $-\sqrt{N_{1-6}}$.
3. A north-south extension of the hail indicator network can be made, and the east half of the network can be abandoned without significantly affecting the statistical properties of the indicator data.
4. The hypothesis of dependence between adjacent indicators cannot be rejected, even though the correlation coefficients are less than 0.50.
5. A period of 3 to 5 years is estimated to be required to detect scale changes of 10 to 25 percent in the hail parameters that might be accomplished by modification attempts. However, there are practical difficulties involved in attaining the conditions assumed in the analysis, one of the most difficult being the problem of handling zero values if complete hail suppression were to be attained.

6. Lack of significant correlation between adjacent areas indicates that a target-control analysis is not feasible for attemping to detect significant changes that might result from a hail modification experiment.
7. Further work is presently being done to develop procedures not dependent on a fixed network for analysis of effects which might be produced in a hail modification experiment.

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