An Energy Method for Relative Estimates of Hail Intensity

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An Energy Method for Relative Estimates of Hail Intensity

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ABSTRACT

A simple instrument was developed to estimate hail energy input per unit area. By using certain simplifying assumptions, the instruments have been calibrated in the laboratory to permit estimates of hail energy input from measurements of dent size and number of dents per unit area. Special effects noted during field use of a large number of these instruments are described.

It is estimated that, although the absolute error in estimating hail energy input may exceed 300 per cent, the error in comparative measurements of hail energy input by this equipment is approximately 50 per cent.

1. Introduction

In the summer of 1959, an evaluation of a hail-suppression project in Northeastern Colorado was undertaken by the Civil Engineering Section of Colorado State University. As an aid in determining the effectiveness of this cloud-seeding project in suppressing hail, a measure of hail intensity was desired. A measuring device was sought that would be inexpensive, simple to operate and maintain, and be capable of giving an objective measure of hail intensity independent of crop damage. This was desirable because crop damage, although a measure of hail intensity, is dependent both on the crop and on its state of growth. It was believed that a measure of hail intensity, in terms of hail input energy per unit area, would produce a better statistic for evaluation than "hail days" which was the only information previously available from this region.

To accomplish the measurement of hail input energy, a hail indicator was designed. The indicator is shown in figs. 1 and 2. The indicator consisted of light foil,[1] heavy foil,[2] and styrofoam. These materials were placed together to form an indicator packet as follows: a 6- × 6- × ½-inch piece of styrofoam was used as the base of the indicator; over this was placed a 2- × 6-inch piece of the heavy foil, positioned at one edge of the styrofoam; these two pieces were then covered and wrapped by a 10-inch square of the light aluminum foil. These packets were placed on stands fastened to fence posts and protected from the wind with a masonite and wooden cover having a 5- × 5-inch opening on top. Approximately 225 of these indicators were located in Northeastern Colorado and Western Nebraska to gather data for the evaluation project.

An example of the condition of these indicators after a hail occurrence is shown in fig. 3. After each hail occurrence, field measurements on each indicator included length and width of the largest dent and the number of dents per unit area. It was then a laboratory problem to interpret this damage in terms of energy input per unit area.

2. Assumptions

To allow laboratory calibration of the energy input of a hailstone, several simplifying assumptions had to be made. They were

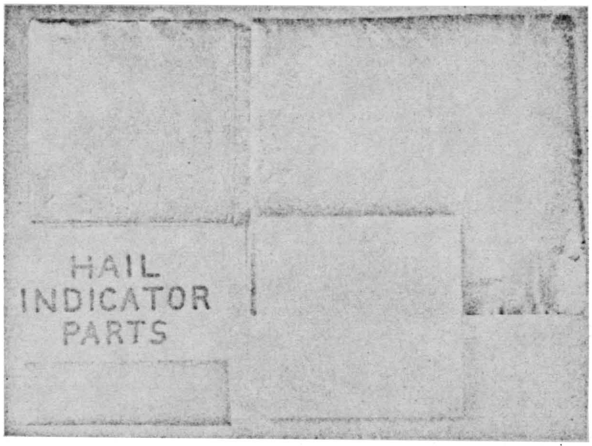

FIG. 1. Hail-indicator packet and component parts.

[1] "Light foil" refers to "Reynolds Wrap, Heavy Duty" household aluminum foil.
[2] "Heavy foil" refers to QQ-A-561B, 2SO aluminum coil sheet, mill finish, 34 gage.

(1) that the hailstones were spherical,
(2) that the hailstones had a density of 0.9 g. per cm^3,
(3) that the hailstones were hard and would not disintegrate upon impact,
(4) that the density of the atmosphere was 1.078×10^{-3} g per cm^3, the density of air at 875 mb and 10C [1, p. 116],
(5) that the viscosity of the air was 1.77×10^{-4} poise, that of air at 10C, [2, p. 2037],
(6) that the coefficients of drag as published by Foster and Bates [3] were of acceptable accuracy.

The first three of these are major assumptions, subject to field verification, and will be discussed later in the paper.

Assumptions 4 and 5 are of minor importance because the viscosity and density of air vary only about 3 per cent per 10C in the range encountered in field conditions. The last assumption is consistent with other sources [4, p. 304].

3. Laboratory procedure

With these simplifying assumptions, it was then possible to determine theoretically the kinetic energy of any diameter hailstone under various wind conditions. The parameters needed were the diameter of the stone, its terminal velocity in still air, and the velocity of the attendant wind.

After the energy of hailstones under various conditions was determined theoretically, an attempt was made to duplicate these conditions in the laboratory. This was accomplished by dropping steel balls upon the indicators. With this method, it was possible to have the same diameter of sphere, input energy, and angle of incidence that occurred in field conditions. This method carried with it the assumption that the variation of density between hail and steel could be neglected. This was tested by striking an indicator with a steel ball and a marble (densities 7.8 and 2.6 g per cm^3, respectively), both having the same diameter, and striking the indicator with the same energy. The assumption was considered justified when no physical differences in the size or shape of the indentations on the indicators could be determined.

The laboratory equipment required for the experiment included an indicator stand, with an adjustable head to simulate various angles of incidence of hailstone attack, and a supply of steel balls of $\frac{1}{4}$-, $\frac{11}{32}$-, $\frac{1}{2}$-, $\frac{3}{4}$-, $\frac{7}{8}$-, 1-, $1\frac{1}{4}$-, $1\frac{17}{32}$-, 2-, and $2\frac{1}{2}$-inch diameters. Each of these sizes of steel balls was then dropped on separate indicators from the height necessary to duplicate the energy of hailstones of identical size having an attendant wind of 0, 20, 40, and 60 mph. The maximum height needed was approximately 30 ft for the larger balls. For this distance, air resistance was considered negligible, and no correction was made for it.

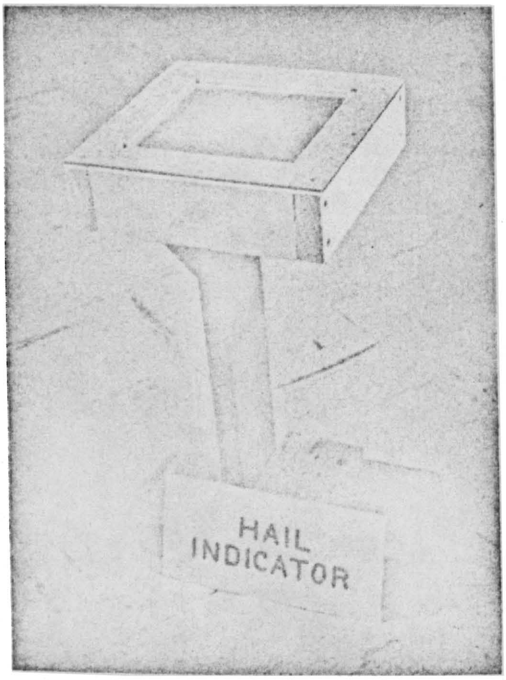

FIG. 2. Assembled hail indicator placed on laboratory test stand.

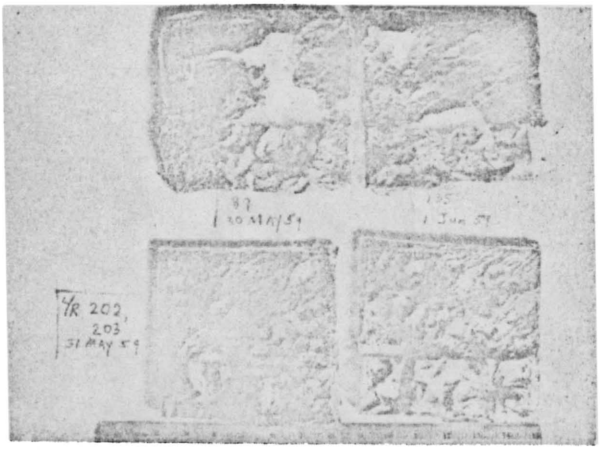

FIG. 3. Indicator appearances after exposure to hailstorms. (Light foil partially removed to show appearance of heavy foil.)

4. Results

It was observed that, when an indicator was struck with a series of steel balls of the same diameter, the last dent received was always the largest.

Apparently the elasticity of the light aluminum foil was such that, when it was hit by a steel ball, the previous dents were reduced in size. This behavior was noted on the light aluminum foil only, in the range of diameters larger than ½ inch.

The shape of dents in the light and heavy foil under the simulated wind conditions was oval, with the major axis up to 2 or 3 times as long as the minor axis.

The physical appearances of indicators tested in the laboratory and of those observed in the field were quite similar. Fig. 4 shows the similarity between an indicator subjected to a hailstorm, and the laboratory approximation of the damage caused by one-inch stones with a 60 mph attendant wind.

Fig. 5 shows energy per stone as a function of the dent "area," A, the product of lengths (in inches) of the major and minor axes of the dent. It will be noted that this relation does not depend upon the wind velocities simulated during the tests.

Using the relations of fig. 5, another graph was prepared wherein hail energy input is shown as a function of number of dents per square inch and dent "area," A. This relation is shown in fig. 6.

If preferred instead of fig. 6, the following approximate equations can be used:

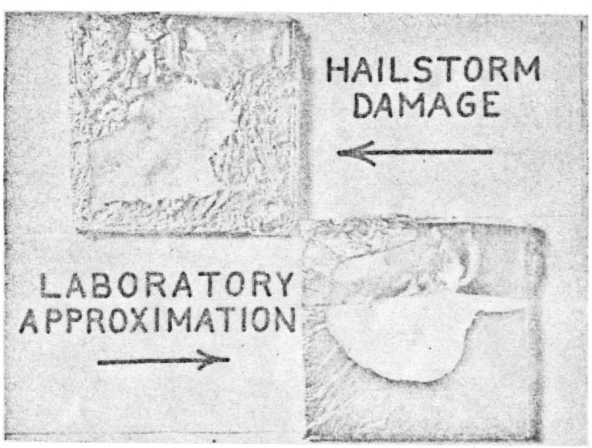

FIG. 4. Example of similarity between indicators tested in the laboratory and indicators subjected to a hailstorm. (Light foil partially removed.)

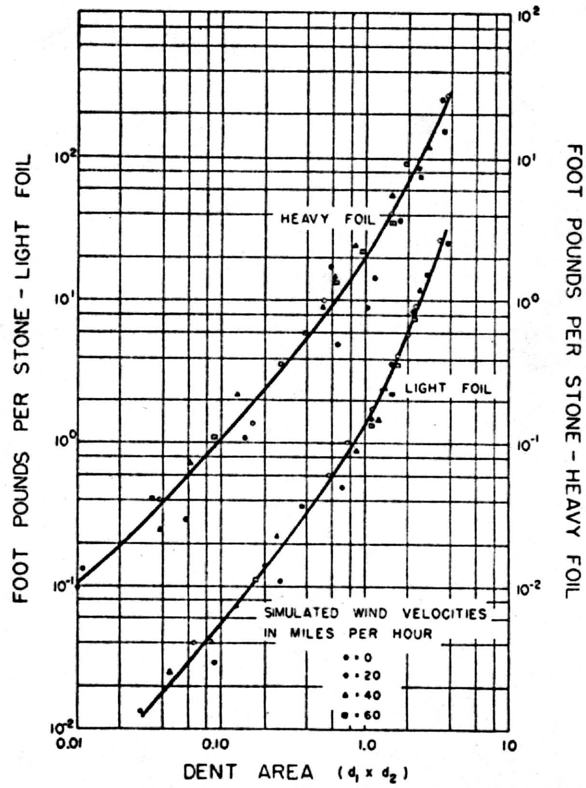

FIG. 5. Energy per stone as a function of dent "area," A, the product of the lengths (in inches) of the major and minor axes of the dent.

Light foil:

$$E = 160n\ A^{1.3} \qquad 0.4 < A < 1.0 \text{ sq inch}$$
$$E = 180n\ A^{2.4} \qquad 1.0 < A < 4.0 \text{ sq inches}$$
$$E = 250n\ A^{1.2} \qquad 0.2 < A < 1.0 \text{ sq inch}$$
$$E = 285n\ A^{1.9} \qquad 1.0 < A < 4.0 \text{ sq inches}$$

} Heavy foil

where

E = ft-lb per sq ft
n = number of dents per sq inch
A = dent "area" in sq inches (product of lengths of major and minor axes of dent).

5. Verification of assumptions

During the field investigations, some verification of the three major assumptions referred to earlier was found. From examination of indicators dented by hail, it is estimated that more than 75 per cent of the hailstones that fell in the area approximated spheres. It was also estimated that greater than 90 per cent of the hailstones were hard. Fig. 7 illustrates a probable exception. Two stones, each approximately 2 inches in diam, fell upon this particular indicator. The

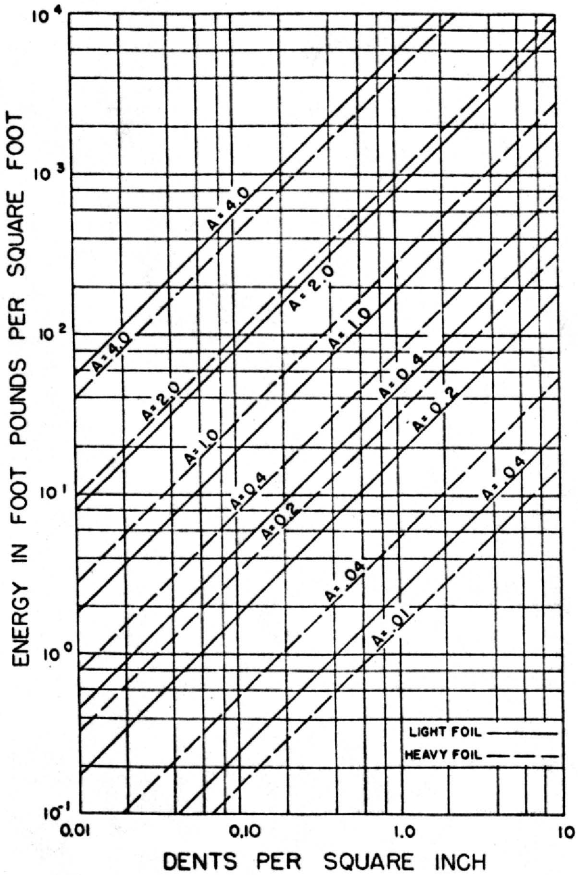

Fig. 6. Graph for determining energy per square foot from dent "area," *A*, and dents per square inch.

dents were approximately the same size, but of different depths, probably due to differences in hardness of stones reported at this location (Akron, Colorado FAA).

The authors have been able to make only one field determination of the density of hailstones. The measured density of the stones was 0.9 g per cm^3, which is consistent with the assumption made.

The effect of error in these assumptions upon the energy input calculations is as follows: a 10 per cent reduction in hailstone density introduces a 10 per cent reduction in the energy number. The amount of error due to variation in hardness is unknown, but it is considered to be small.

Departures from the assumptions made for the laboratory calibration all tend to lessen the energy number calculated from the hail indicators, so that the calculated energy per square foot represents an approximation of the maximum amount of energy necessary to produce the particular number and size of dents observed on an indicator.

The field-measurement technique described previously, wherein only the largest dent dimensions were measured, also tended to increase the calculated energy numbers. If more resources are available, this limitation can be minimized by measurements of size distribution of dents, and a more precise approximation of hail energy can be obtained by summing energy values for individual size classes using fig. 6.

6. Special effects

There are a few special effects that occurred in the use of this type of indicator. It was noted that smooth dents ranging in diameter from 0.10 to 0.40 inch were repeatedly noticed on the light aluminum foil. These dents were observed on the light aluminum foil only and were always extremely smooth. It was later shown in the laboratory that these were the marks left by heavy rain and that, if the rain drops were large, the pattern of the styrofoam grains would be impressed upon the light aluminum foil. This phenomenon was also noticed on the field indicators.

High winds also had a marked effect on the appearance of the light aluminum foil. Fig. 8 shows an indicator after exposure to winds of approximately 60 mph. The characteristic oval-shaped dents produced by hail accompanied by high wind can be observed. In many cases involving hailstones of larger diameters, horseshoe-shaped tears in the light foil were observed, similar to those produced in the laboratory under simulated conditions of high wind. In some cases, wind and hail intensity were sufficient to tear away most of the light foil.

These hail indicators have been subjected to only minor vandalism, mainly from birds, who pecked holes in the indicators. The only other

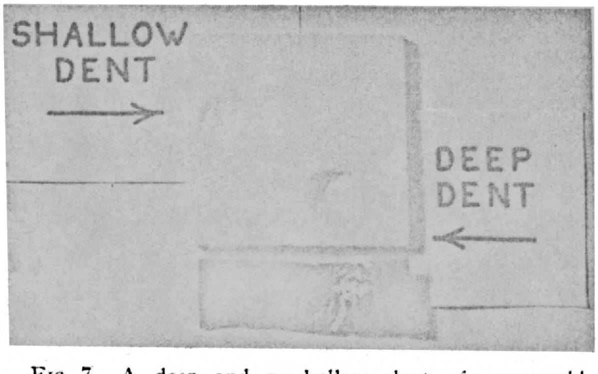

Fig. 7. A deep and a shallow dent of comparable area found on an indicator exposed to a storm of both soft and hard stones.

vandalism has been the recorded thumbprints of inquisitive residents of the hail suppression area.

7. Limitations

In comparing the energy numbers calculated from the light and heavy aluminum foils, it is estimated that the maximum probable inconsistency between the two measurements is approximately 100 per cent. Of the two foils, the heavy foil is probably the best indicator because of its superior recording ability, although it is more difficult to measure dents of large diameters on this foil.

It is estimated that the difference between the theoretical energy input determined from the indicators and the actual energy of hail that fell in a particular hailstorm may be as high as 200 to 300 per cent. However, this is not considered critical, because a means of comparison between hail intensity of different hailstorms or of the same hailstorm at different points, and not the actual energy involved, was desired. Comparison of closely spaced indicators, exposed to the same storms, indicates that with careful reading the comparative error of energy numbers probably does not exceed 50 per cent.

The statistic of hail energy input per unit area is considered an improvement over the previous statistic of "hail days." The inaccuracies involved, though seemingly high, are considered acceptable because energy numbers exceeding 1000 ft-lb per sq ft have been recorded in the field. This range allows a comparison of hail intensities on an order-of-magnitude basis so that errors of even 100 per cent are considered acceptable.

As an illustration of what the magnitude of the energy number of a hailstorm might mean in terms of crop damage, it has been noted that energy numbers less than 10 ft-lb per sq ft usually produce negligible damage to field crops. Energy numbers from 10 to 100 ft-lb per sq ft are usually associated with moderate crop damage, and energy numbers over 100 ft-lb per sq ft are generally coincident with heavy or complete crop damage. These categories should be considered as tentative only, since they are based on a limited number of observations and not on a systematic study of the relations between crop damage and hail energy numbers.

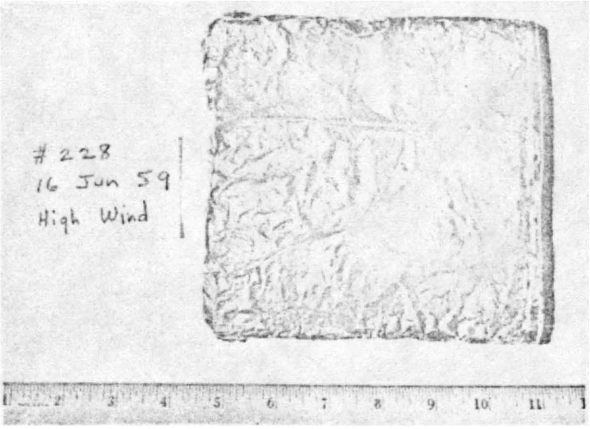

FIG. 8. Hail indicator after exposure to heavy rain, high winds, and hail.

8. Summary

As an aid in evaluation of a hail-suppression project, a hail-indicating device consisting of two types of aluminum over styrofoam has been developed and calibrated in the laboratory. Dents in the indicator are interpreted in terms of hail energy input per unit area. This statistic is considered to be a better measure of intensity of hail than "hail days" or crop damage.

Some field verification has been found for the major assumptions that were made in the calibration of the indicators. Further information on the physical characteristics of hailstones is desirable for further development of the indicators.

Use of the indicators has shown them to be simple and inexpensive to construct and maintain. Comparative measurements from adjacent indicators show that hail intensity can be measured by this method within acceptable limits of accuracy.

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