Areal-Temporal Variations of Hail Intensity in Illinois

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ABSTRACT

Four forms of hail data in Illinois were analyzed to obtain indirect measures of the areal and seasonal variations in hail intensity. These data were also examined to ascertain which hail characteristics correlated best with crop damage.

The frequency of intense hail in the crop season (May–October) was found to increase with time, reaching a maximum in September. Insurance statistics indicated that corn damage from hail was usually greater in July than in the later months because corn was more susceptible to damage in July. Observations from a mesoscale network in central Illinois indicated that hailstone sizes and number (volume of ice) and durations of hailstorms related moderately well with crop-hail damage, but that strong surface winds were more closely related. Significant areal variations of hail intensity were found, with some portions of Illinois experiencing intense hail six times more often than other areas.

1. Introduction

The lack of any systematic measurement of hail intensity in Illinois coupled with the increasing need for such information, for both applied and scientific purposes, led to a climatological study of data that could provide indirect measures of hail intensity. All known forms of hail data in Illinois were investigated and results compared to obtain measurements of the areal and seasonal variations in intensity. Another desired goal of this study was to delineate and quantify, if possible, the hailfall conditions that produce crop damages in Illinois.

Hail intensity is here defined, in general, as the total impact energy during a hailstorm at a point. Thus, this intensity integrates the size and density of hailstones, the number of stones per unit area, the fall velocity, angle of fall, and the duration of hail at a point.

Certain laboratory tests, field experiments, and theoretical calculations concerning the intensity of hail have been performed (Collins and Howe, 1964; Camery and Weber, 1953; Hella and Stoa, 1964; Hail Insurance Adjustment and Research Association, 1955), and these have provided measures of damage associated with varying hail sizes and to some degree with hail intensity. However, the only effect to obtain actual field measurements of hail intensity over an area for any length of time was performed in northeastern Colorado during a 5-yr hail modification project (Schleusener, 1963; Schleusener and Sand, 1964).

Four sets of hail data from Illinois, each containing different indirect measures of intensity, were analyzed. One set of data was a detailed 20-yr record of all hail occurrences at a point. The second was based on detailed observer reports of hailstorms in a central Illinois network. The results from these point and network data should have meaning in areas with a similar climate. The third set of Illinois data analyzed consisted of original Weather Bureau substation records of estimated intensity, and the fourth set consisted of detailed corn-hail insurance records for Illinois. Both of these types of data are available for other states and provide a potential means for obtaining widespread estimated intensity information.

2. Hailfalls at a point

Data. In the 1946–1965 period detailed records on all hail occurrences at Urbana (Fig. 1) were kept. Maximum stone sizes, time of hail occurrence, duration of fall, and the maximum wind gust at the time of hail were measured. There were 99 hailstorms (Table 1), although in five instances two or more hailstorms occurred on one day, resulting in hail on 91 calendar days which is more than the 60 days expected in an average 20-yr period for Urbana (Changnon, 1963). Because of the infrequency of hail, the July (2 storms) and August (8 storms) data were grouped, as were the September (6 storms) and October (2 storms) data.

Results. Twenty of the 99 hailstorms produced stones measuring over ½ inch in diameter. Only 5 hailstorms produced stones over 1 inch and just 2 of these occurred in the crop growing season, May–October. The frequency of ½ inch or larger stones was expressed as a per cent of the total monthly hailstorms, showing relatively high percentages for April and the July–October period.

The wind data presented in Table 1 indicate that fall hailstorms were associated with slightly higher gusts than those in the earlier part of the growing season.

TABLE 1. Characteristics of hail at Urbana, Ill., 1946–1965.

	Mar.	Apr.	May	June	Jul.-Aug.	Sep.-Oct.	All other months	Totals
Total hailstorms	19	20	11	17	10	8	14	99
Maximum stone sizes								
($<\frac{1}{2}$ inch)	15	14	10	14	7	6	12	79
($\frac{1}{2}$–1 inch)	3	4	1	3	2	1	2	15
(>1 inch)	1	2	0	0	1	1	0	5
Stones $\frac{1}{2}$ inch or larger as per cent of total	21	30	9	18	30	25	14	—
Average peak gust (mph)	24	29	25	22	27	31	24	—
Average hailfall duration (min)	2.3	2.8	3.2	2.3	1.4	1.5	2.0	—
Intensity value	12	24	7	9	11	12	7	—

However, the small sample restricts the significance of this minor difference. The larger stone size percentages and the average gusts shown in Table 1 suggest that a hailstorm in the July–October period, and especially one in September–October, would produce considerably more crop damage than one in the May–June period.

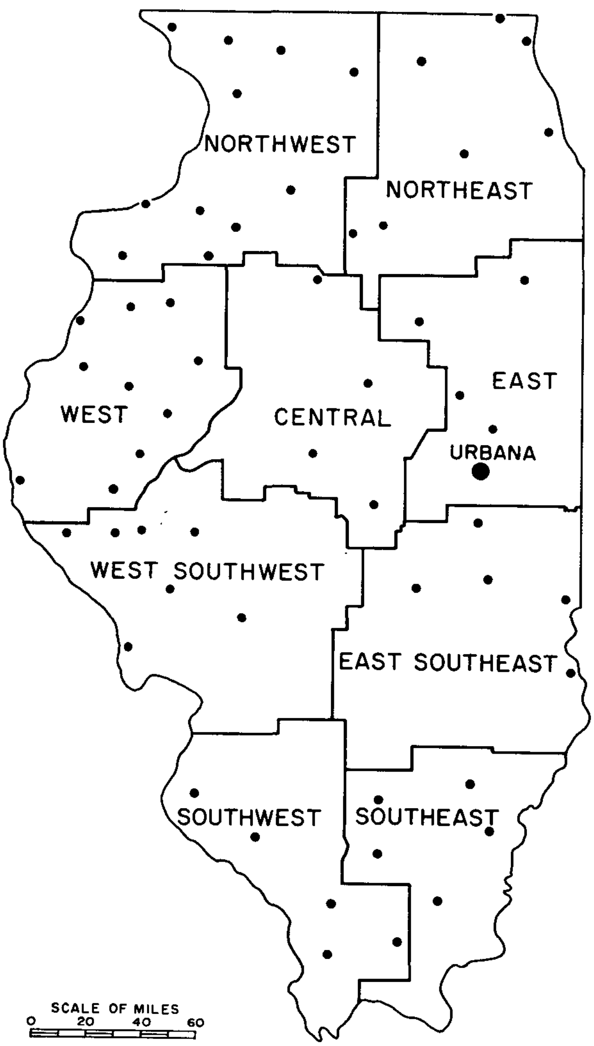

FIG. 1. Data stations and crop-reporting districts in Illinois.

However, the May and June hailstorms have much longer average durations than those in the late season, and this, as a measure of the volume of ice, acts to increase the relative intensity of the May–June storms.

Three monthly parameters, i.e., number of larger stones, average wind gust, and average duration, were multiplied to obtain an empirical monthly intensity value (Table 1). The calculated value for April (30% mph$\times$29$\times$2.8 min$=$24.4) is highest, but during the crop season the intensity value increases with time beginning in May and ending with the highest value in the September–October period.

3. Relations between network hail parameters and crop damages

Data. Over a 5-yr period, 1958–1962, 1100 farmers acting as volunteer hail observers reported the occurrence of hail in a 22,000 mi^2 network in central Illinois (Wilk, 1961). These observers supplied 738 reports describing, from 87 hail days, the date and time of hail occurrence, duration of hailfall, maximum and average stone sizes, number of stones per square foot, incidence of damaging winds, and the occurrence of crop damage to corn and soybeans. Crop damage was reported as no damage (644 reports from 79 days), little damage (65 reports from 31 days), and much damage (29 reports from 21 days).

These network data allowed the evaluation of the hail parameters associated with the three levels of crop damage, and also provided measures of seasonal variations of hail intensity as reflected by the crop damages.

Monthly crop damage reports. The number of reports and hail days per month are shown in Table 2. June led in the number of damage reports (little and much), and May, July and September had nearly equal numbers. Comparison of the number of damage reports per month with total reports (Table 2) produced percentages indicating that hailstorms in late summer produced crop damage more frequently than those that occurred earlier in the crop season.

Maximum hailstone sizes. About 14% of all 738 hailstorms had maximum stone sizes of 1 inch or more in diameter, whereas the Urbana point data revealed that only 5% of the total were this large. The percentage of

TABLE 2. Monthly days of hail and number of hail reports for each crop damage class.

	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Total
Total days of hail	15	22	19	15	8	4	2	87
No damage	212	217	152	30	10	13	10	644
Little damage	2	13	30	6	4	10	0	65
Much damage	3	3	10	9	1	3	0	29
Total reports	217	233	192	45	15	26	10	738
Per cent of reports with damage	2	7	21	33	33	50	0	13

all hailstorms with relatively large stones ($\frac{3}{4}$ inch diameter or greater) increased during the hail season representing 22% of the April incidences, 30% of those in May, 39% in June, 42% in July, 53% in August, and 46% of the September total. The temporal increase in the crop damage percentage frequencies (Table 2) agrees with this temporal increase in large stone occurrences.

The maximum stone size data separated by damage categories are shown in Table 3. Fifty-nine per cent of all much-damage cases were associated with $\frac{3}{4}$ inch or larger stones, whereas these large stones were associated with only 28% of the no-damage reports. Importantly, 41% of the much-damage reports occurred with $\frac{1}{2}$ inch or smaller stones.

Areal number of hailstones. The average number of stones per square foot for the 644 no-damage reports was compared with the average for the 94 damage (little and much) reports (Table 4). The average number of stones per square foot associated with no damages was 27, or 10 less than that with damages. If crop damage is closely related to the total amount of ice for the same amount of damage, then in a given area the number of small stones should be greater than the number of large stones. However, the damage cases associated with the smaller stone sizes ($\frac{1}{2}$ inch or less) had fewer stones per square foot than did the damage cases with the larger stone sizes (1 inch and larger). This suggests that another factor, other than stone size and number, is important in the production of crop-hail damages.

Duration of hailfall. Another parameter investigated using these network data was the duration of hail as related to crop damage. Results in Table 5 show that duration increased with the amount of damage. Longer hail durations imply the occurrence of a greater number of stones, or as Schleusener (1963) suggests, a greater volume of ice per unit area. The data on the average number of stones in Table 4 generally support this conclusion. The ratio of the average durations between damage (little and much) and no damage is 1.45 (9.5÷6.5), and the ratio of the average number of stones between crop damage and no damage (Table 4) is 1.37 (37÷27).

Wind with hailfalls. The reported occurrences of damaging winds with crop damage cases and with no-damage cases are shown in Table 6. All 29 reports of much crop damage from hail listed damaging winds. Almost all (95%) of the 65 little-crop-damage reports were associated with damaging winds. Only a small percentage of the 644 no-damage reports listed damaging winds, but the number of such reports totaled 96 which exceeds the 91 reports of damaging winds with hail damage to crops.

Although no actual wind speeds are known, these data definitely indicate that crop damage from hail is

TABLE 3. Frequency of reports of maximum stone size for different size classes expressed as a per cent of all reports for each crop damage category.

	Maximum stone diameter, inches				
	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	>1
Much damage	24	17	24	21	14
Little damage	25	35	25	12	3
No damage	40	32	17	8	3

TABLE 4. Average number of stones per square foot for various stone sizes.

	Number of stones for maximum stone diameters, inches					
	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	>1	All stones
No damage	23	29	30	33	26	27
Little and much crop damage	27	33	32	42	40	37

TABLE 5. Relation of duration of hail at a point and crop damage.

Duration	No damage	Little crop damage	Much crop damage	Little and much crop damage
Average (min)	6.5	8.7	12.5	9.5
Median (min)	5	5	10	7

TABLE 6. Occurrence of damaging winds with hailfalls.

	Per cent of all hail reports in each damage and stone-size category occurring with damaging winds		
	Stones of $\frac{1}{2}$ inch diameter or less	Stones of $\frac{3}{4}$ inch diameter or larger	Total reports
Much crop damage	100	100	100
Little crop damage	97	92	95
No crop damage	12	14	13

TABLE 7. Hail intensity reports and insurance intensity values for each district in Illinois.

District	Number of stations	Average number of reports per station	Per cent of total district reports			Regional insurance intensity value (loss cost, $)
			Light intensity	Moderate intensity	Heavy intensity	
NW	11	26	75	16	9	0.73
NE	7	27	78	17	5	0.77
W	10	21−	78	15	7	0.46
C	4	24+	72	18	10	0.50
E	5	19+	65	28	7	0.39
WSW	7	28	83	9	8	0.57
ESE	5	17	79	14	7	0.25
SW	5	25	69	24	7	0.68
SE	5	11−	90	4	6	0.60

almost always associated with high winds also capable of producing damage. Apparently, small or large stones that fall without simultaneous damaging winds will seldom produce serious damage to corn and soybean crops; however, the simultaneous occurrence of hail and damaging winds does not always produce crop damage.

4. Areal and temporal variations of hail intensity in Illinois

Data. Hail data from U. S. Weather Bureau records and crop-hail insurance records were used to analyze areal and temporal variations of intensity in Illinois. During the 1928–1942 and 1946–1948 periods, Weather Bureau cooperative observers throughout the country reported the intensity of hailstorms by the terms "light, moderate, or heavy." Weather Bureau instructions (U. S. Department of Agriculture, 1924) issued for these definitions were vague, but generally implied the degree of damage. Although subjective, any hailstorm defined by most observers as one of heavy intensity was likely a serious damage-producing local hailstorm, whereas a storm defined as light intensity by most observers was likely one that did no damage. Thus, these subjective measures probably are a relatively good measure of hail intensity. The 18-yr period of the data also acted to cancel observer differences and reporting bias.

Data from 59 cooperative substations in Illinois (Fig. 1) with acceptable hail records were used in the analysis. To further overcome the subjectivity problem, the intensity data from these stations were grouped according to the nine crop-reporting districts in Illinois (Fig. 1). These data served as measures of the areal and temporal variations in hail intensity in the state.

The Crop-Hail Insurance Actuarial Association provided a listing, based on corn data, of all the individual storm-day losses in Illinois during the 1957–1964 period. These were expressed as storm-day loss costs [amount of loss (dollars) divided by the liability (dollars) in the area of loss, times $100]. The median storm-day loss cost value determined for each month was defined as the monthly insurance intensity value. However, the great change in a corn plant's susceptibility to damage during the growing season (Hail Insurance Adjustment and Research Association, 1955) is a factor integrated with the hail intensity in the insurance intensity value, and and thus seriously limits use of this value in making monthly comparisons of intensity. Mean loss cost values also were computed from the historical insurance data for each crop-reporting district in Illinois, and these were labeled as regional insurance intensity values.

Areal and seasonal variations. Weather Bureau data and insurance data on hail intensity by crop-reporting districts are given in Table 7. Previous findings based on long hail records (Changnon, 1962) agree well with the district averages in Table 7, indicating that the 18-yr period was representative. A greater percentage of all hailstorms in the E, C (central), and SW districts were more intense (moderate plus heavy) than were those in the other districts of Illinois. In contrast, the regional insurance indices were highest in the NW, NE, SW, and SE districts and lowest in the E and ESE districts.

From the Weather Bureau data, the monthly numbers of moderate and heavy reports per district were expressed as a per cent of the monthly total hail occurrences (Table 8). The statewide monthly averages indicate that the relative frequency of the more intense hail occurrences decreases steadily from March through June, but then increases rapidly in July and maximizes in September.

Further variations in the different hail intensities during the crop season are revealed in Table 9. Sixty

TABLE 8. Per cent of regional monthly hail incidences reported as moderate or heavy intensity.

District	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
NW	20	21	15	36	25	18	36	21
NE	13	17	25	18	21	10	50	20
W	11	16	27	18	16	15	30	28
C	33	18	13	0	32	58	100	0
E	27	32	21	25	62	82	100	20
WSW	25	16	5	10	39	10	22	0
ESE	16	20	5	22	46	0	0	0
SW	59	26	22	8	20	9	14	17
SE	7	10	13	2	2	0	0	0
Statewide average	23	20	16	15	29	23	39	12

TABLE 9. Frequency of different hail intensities in the June-September period expressed as a per cent of total hail reports per district.

Intensity classes	NW	NE	W	C	E	WSW	ESE	SW	SE
Light	69	79	78	62	40	82	80	88	95
Moderate	14	15	13	19	46	2	15	9	2
Heavy	17	6	9	19	14	16	5	3	3
Moderate+heavy	31	21	22	38	60	18	20	12	5

per cent of the June–September hailstorms in the E district were classified as moderate to heavy intensity, whereas only 5% of the hailfalls in the SE district were of similar intensity.

The median monthly storm-day loss cost values, or intensity values derived from the corn damage insurance data, ranges from a low of $0.0001 in May and September to a high of $0.0010 in July. The value in both June and August was $0.0003. The high in July coincides with the great susceptibility for damage to corn in July (Hail Insurance Adjustment and Research Association, 1955).

5. Comparisons

Comparison of seasonal intensity variations in Illinois. Monthly indices of hail intensity based on the various hail data in Illinois are presented in Table 10 for the May–October period. The U. S. Weather Bureau indices shown were derived from the statewide average monthly values of intensities in Table 8. These percentages of all storms per month classed as moderate or heavy intensity were divided by the lowest value, which was 12% in October, to provide the Weather Bureau index values in Table 10.

The monthly percentages of central Illinois hail reports that listed damage (Table 2) were divided by the lowest value, 7% in May, to obtain the central Illinois indices in Table 10. The Urbana monthly intensity values (Table 1) were divided by the lowest value, 7 in May, to derive the Urbana intensity indices. The insurance-derived intensity values were adjusted by dividing by the lowest value, $0.0001 in May and September, and the resulting indices also appear in Table 10.

A graph based on these four sets of intensity indices appears in Fig. 2. The three forms of the Illinois climatological data have their highest intensity indices in September, with July and August values ranked as next highest. The monthly insurance intensity indices maximize in July, which precedes the hail intensity peak

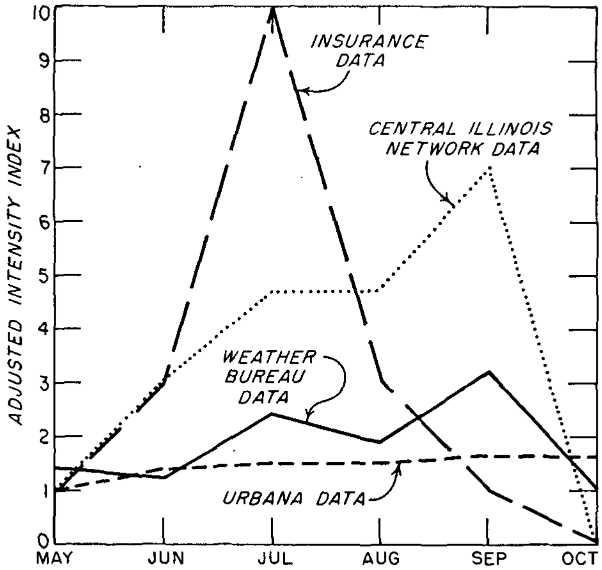

FIG. 2. Seasonal variations in hail intensity exhibited by different types of Illinois data.

shown by the other data. This July peak in the insurance data occurs because the corn crop is more susceptible to damage in July, and not because the intensity of hailstorms is greatest in July.

TABLE 10. Various monthly intensity indices in the crop season.

	May	Jun.	Jul.	Aug.	Sep.	Oct.
Weather Bureau index	1.3	1.2	2.4	1.9	3.2	1
Central Illinois index	1	3	4.7	4.7	7	0
Urbana index	1	1.3	1.5	1.5	1.6	1.6
Insurance intensity index	1	3	10	3	1	0

Linear correlation coefficients were calculated for the four sets of monthly intensity indices (Table 10). The Weather Bureau intensity indices had a correlation of 0.94 with the central Illinois indices, 0.89 with the Urbana indices, and 0.39 with the insurance indices. The central Illinois indices had coefficients of 0.86 with Urbana data and 0.36 with insurance data, while the Urbana indices had a coefficient of 0.48 with the insurance indices. Thus, strong associations exist between the Weather Bureau, central Illinois, and the Urbana indices, but none of these three sets of intensity indices correlated well with the insurance indices.

Comparison of areal intensity variations in Illinois. The intensity data from Weather Bureau stations, grouped by nine districts (Fig. 1), and the insurance records in these districts provided two measurements of the areal variability of hail intensity in Illinois.

The regional insurance intensity values (Table 7) were divided by the lowest loss cost value, $0.25 in the ESE district, to obtain regional insurance indices (Table 11). The heavy-intensity percentages from the Weather Bureau data (Table 9) were divided by the smallest number, 3% in the SW and SE districts, to obtain regional climatological indices. To allow further comparison both sets of district values were ranked, with rank 1 being the largest district value and rank 9 the lowest.

Comparison of the values and their ranks shows partial agreement. Both intensity expressions indicate relatively high regional values in the NW and WSW districts and a generally lower number of high intensity

TABLE 11. Regional hail intensity indices in Illinois.

	Districts								
	NW	NE	W	C	E	WSW	ESE	SW	SE
Insurance indices	2.9	3.1	1.8	2.0	1.6	2.3	1.0	2.7	2.4
Rank	2	1	7	6	8	5	9	3	4
Climatological indices	5.7	2.0	3.0	6.3	4.7	5.3	1.7	1.0	1.0
Rank	2	6	5	1	4	3	7	8–9	8–9

hailstorms in the W and ESE districts. Values for the other five districts are not in agreement.

The disagreement in these two expressions may result from the fact that the insurance data are affected by inadequate sampling or by regional differences in the target, that is, the susceptibility of the various crops to damage. The statewide pattern of intensity variations shown by the climatic indices is in agreement with findings from past hail-days research in Illinois (Changnon, 1962).

6. Conclusions

Various estimated measures of hail intensity determined from point, network, and statewide climatological data in Illinois indicated that the hail intensity per storm increases during the crop growing season, reaching a peak in September. Insurance-derived intensity values indicated a peak in July, but this occurred largely because July is the peak month of crop susceptibility to hail damage.

The Weather Bureau hail data indicated that sizable areal variations in intensity exist within Illinois. Intense hailfalls occur in northwestern and central Illinois six times more often than in southern Illinois. Since the results from these data agreed with other findings in Illinois, these data from other states could be analyzed to provide useful measures of intensity.

The central Illinois mesonetwork data revealed that the occurrence of crop-hail damage was closely associated with the occurrence of damaging, high-speed surface winds. These data also indicated that crop damage, in general, was related to the occurrence of relatively large ($\frac{3}{4}$ inch or larger) stones, long durations of hailfall, and with more numerous stones on the ground, although in many instances heavy crop damages occurred with stones of $\frac{1}{2}$ inch or less in diameter. As long as strong surface winds do not occur, a considerable volume of large hail can fall without producing significant damage to corn and soybean crops.

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