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SINGULARITIES IN SEVERE WEATHER EVENTS IN ILLINOIS

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Introduction

Detailed analysis of severe weather events in Illinois has revealed that on certain dates in the March-October period these events occur either frequently or infrequently. These dates have been identified as singularities and are noticeable in the daily occurrences of heavy 24-hour rainstorms, thunderstorms, hailstorms, tornadoes, and damaging lightning in Illinois. To large extent these events are inter-related weather phenomena and consequently show many common temporal singularities.

Using long climatological records of the U. S. Weather Bureau for Illinois, the frequency that each calendar date experienced thunderstorms and the four other related forms of severe weather was determined. Examination of the daily frequencies for each of the five events revealed the presence of several apparent singularities, usually of 1 to 3 days duration, when the severe weather event occurred with either high or low frequency. After investigating the daily frequencies of these five events on a separate basis, the data were compared and analyzed to search for composite singularities. Statistical tests were applied to measure the reality of these composite singularities. Other meteorological data such as pressure and temperature were investigated to explain and corroborate the severe weather singularities.

The annual maximum of each of these five events occurs during the warmer half-year in Illinois, but the mode of the activity varies between events. Tornadoes maximize in April-May, lightning in July-August, thunderstorms in June, hailstorms in May-June, and rainstorms in June-July. Even though these events maximize in different months, the time series of occurrences have many corresponding highs and lows of occurrences on particular dates.

Knowledge about severe weather singularities has importance as basic descriptive climatological information. Undoubtedly, knowledge of such events could be used as a forecasting aid. Inasmuch as these severe weather events are largely produced by macro-scale atmospheric disturbances passing across the Middle West, any tendency for re-occurrence on particular dates, of groups of dates, suggests that in many years these systems tend to move from their areas of gensis on nearly the same dates. Obviously, in some years the series of event6 do not conform to the long-term pattern of time sequence. However, the findings

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presented in this paper indicate the presence of several singularities in the occurrence of severe weather events in. Illinois.

Data

The data on which this study was based were obtained from published and unpublished data of the U.S. Weather Bureau. To obtain data on the dates of hail and thunder occurrence, the original records of all substations in Illinois were analyzed. Much of this information was obtained by machine processing of Illinois records on IBM cards. (1) The data on the occurrence of tornadoes, heavy rainfall, and damaging lightning were obtained from the written summaries in the published Climatological Data for Illinois. (2) The periods of record examined for the various events varied according to availability of the data and the need for sufficient data to furnish representative results. In all instances, data for the March-October period were employed. Occurrences of these five forms of severe weather are too infrequent in the November-February period to warrant study of daily frequencies.

The thunderstorm data used were for the period of 1925-1959. The greater frequency of occurrence of this event made a 35-year period of record quite adequate. A thunderstorm day was defined as a day when three or more stations in Illinois reported thunder. Based on this definition a total of 2978 thunderstorm days occurred.

The hail data used in the study were for the 1901-1959 period. Any date that had one or more stations reporting hail was defined as a hail day. There were 2776 hail day occurrences in this 59-year period of records.

After careful examination of the rainfall statistics a day with severe rain was defined as a day when 5 percent of the stations in Illinois experienced 2.0 inches or more rainfall in 24 hours. Such an amount is equaled or exceeded only once every 5 years at a given point in Illinois. (3) Five percent of the stations were used to adjust for the varying number of stations during the 1914-1960 period which was the period analyzed for the heavy rainstorms. Five percent of the total stations in 1914 was five whereas in 1960 five percent was ten stations. Based on this definition of a day with heavy rainstorms, it was found that 949 such days had occurred in Illinois in the 47-year period analyzed.

A tornado day was defined as a day when one or more tornadoes occurred. Records used were those for 1914-1960, and this period included all of the reliable data available on tornadoes in Illinois. A total of 171 tornado days occurred. Although this might be considered to be a questionable size of sample for this type of study, the tornado data were included for comparison with the other severe weather events.

A day with damaging lightning was a day when either property damages or personal injury was caused by lightning. All data readily available on this topic were employed and this included published records for the 1914-1948 period. In this 35-year period a total of 421 days with damaging lightning occurred in Illinois.

Other climatological data were employed in this study. Statewide estimates of daily relative humidity values at 12 noon, pressures at 6 P.M., maximum temperatures, and percentages of possible sunshine were computed using the average daily values of these phenomena for Chicago, Moline, Peoria, and Springfield. Station data at Peoria were for the 1905-1948 period, whereas the data from the other three stations were for the 1901-1948 period.

Methods of Analysis

Singularities, spells, and anomalies in a time series can be defined in several subjective ways. Statistical definitions are still argumentative and not as objective as one might desire. (4, 5) There is even some scientific disagreement as to the proper definition of singularities, spells, and anomalies. (6) One may wonder why anyone might be foolish enough to attempt analyses in this abyss of semantic and scientific confusion. This confusion probably explains the lack of research into singularities among American meteorologists and climatologists. Interest and research in singularities have been more extensive in Europe than in America, possibly because the European scientists have had longer climatic records at their disposal. However, in recent years, American interest in Bowen's theories concerning the effect of meteoric dust showers on rainfall occurrence has led to increased research relating to singularities.

Singularity identification can only be accurately performed when climatological records are sufficiently long to remove the random fluctuations in a time series that are a result of inadequate sampling. Until such data become available, one must be content to define singularities in some subjective or semi-objective manner. Examination of the literature indicates that there have been several methods employed to identify and define singularities. For the sake of convenience and clarity, frequent or infrequent numbers of occurrences of an event which exceed a specific level on a calendar date shall hereafter be referred to as a singularity in this paper. For peaks or troughs of two or more events to be classed as a composite singularity, the dates of occurrence had to occur within a period of three consecutive calendar dates.

One simple way to define a singularity in a time series is to subjectively consider any date with an apparent high or low frequency value as a singularity. Such a procedure is often based on folklore concerning weather phenomena.

A subjective procedure can be refined by selecting mathematical limits of frequency which must be exceeded in order to qualify the event as a singularity. Others have improved on this method by substantiating their identification procedures by using related atmospheric data, such as upper air data, which also show anomalies on or near the date of the selected singularity. (7) Another approach used to define singularities is to employ statistical tests and measurements which attempt to identify the singularity as being real, or significant, or as representing a frequency above the "noise" level of random sampling. (4, 6, 8,) The number of methods one can employ to test singularities is almost as numerous as the number of persons who have studied the problem.

In this paper, singularities were defined using four different procedures of identification. Those singularities which were identified by each of these procedures also were compared by a fifth method. Certain available climatological data including pressure, temperature, relative humidity, and sunshine were utilized to offer explanations of the possible causes of the singularities.

Initially, each of the five events was analyzed separately. Examination of the daily frequencies of all five events indicated that the analysis should be performed using 3-day moving totals. Low daily frequencies in the lightning and tornado data were brought to a more reasonable analytical level by using 3-day totals, and 3-day moving periods also helped smooth and filter some of the abrupt" day-to-day variations apparent in the data. The daily frequencies, as expressed by the 3-day moving totals, also were expressed as a percentage of normal. A normal or base value was necessary in order to measure the relative magnitude of the peaks and troughs because comparison of their daily frequencies without adjustment to a normal was difficult owing to the great seasonal variation in all five events. These normals were computed for consecutive 10-day periods. Using the percentage data, all of the high and low daily values which exceeded the standard deviation value were selected for each event and identified as event peaks and troughs. In all but one event, exactly 13 peaks and 13 troughs exceeded the standard deviation. Thirteen values represent approximately five percent of the total daily values. Those daily values exceeding two standard deviations were identified as event singularities.

The peaks and troughs of the individual events were compared to identify composite singularities. Because of the paucity of data on lightning days and tornado days, two investigations of composite singularities were performed. The first dealt with singularities as determined from the thunder, hail, and heavy rainfall statistics which are considered to represent sufficient sampling of their respective events to ob tain reliable daily frequencies for a time series. These 3-event composite singularities were examined statistically for significance.

Using these 3-event composite singularities, another subjective definition for singularities was employed. That is, when a trough and a peak occurred within a 7-day period these associated peaks and troughs attained a time-change significance and each was classified as a singularity.

The second investigation of composite singularities incorporated data from all five events. The low frequency of occurrence of the lightning and tornado days, especially in March, September, and October, resulted in a number of consecutive days with 3-day averages of zero. Of course, these zero values might be singularities but their presence does affect any statistical determination of singularities if their data are incorporated with the thunder, hail, and tornado data. Another selection of severe weather singularities was made by comparing the results of four other methods of definition.

Thunderstorm Days. The peak in the thunderstorm season in Illinois occurs in June, as shown in Figure 1. Except for minor recessions in early June and early August, the normal curve of thunderstorm day occurrences has the characteristic shape of annual distribution found in continental climates with a smooth increase in spring, a peak in mid-summer, and a smooth recession in fall. The one date with the highest frequency of thunderstorm days was June 12 which was classified as a thunderstorm day 24 times in the 35-year period. Notable highs and lows in the frequencies of the 3-day moving totals are apparent, but they are difficult to compare and evaluate because of the constantly changing seasonal distributions throughout the 8-month period. To compensate for this problem, the daily frequencies for the 3-day moving totals were expressed as percentages of normal, and the resulting graph is shown in Figure 2. Thirteen peaks exceeded 20 percent of normal and 13 troughs were 18 percent or more below normal.

In Tables 1 and 2 the peaks and troughs which exceeded one standard deviation are listed and ranked based on departure from normal. A total of 13 peaks and 13 troughs exceeded the standard deviation. As shown in Table 1, there were five peaks which had daily values more than twice the standard deviation. The probability that these five peaks are not random variations is 95 percent based on the assumption that the sample is representative of the true distribution. These five peaks were identified as singularities for thunderstorm days in Illinois and are so indicated on Figure 2. In Table 2, two troughs in the thunderstorm frequencies are shown to exceed two standard deviations. These also were classed as thunderstorm singularities and are also indicated on Figure 2.

Hail Days. In Figure 3 the daily frequencies of hail days in Illinois are shown. The normal curve reveals that hail day frequencies increase very rapidly in March, reaching their annual maximum in late May. The single dates with the greatest number hail day occurrences were May 9 and June 13 with 24 such days each in the 59-year period. The hail day frequency (Fig. 3) diminishes rapidly in late June and again in late August. The curve based on the 3-day moving totals in Figure 3 has several prominent high and low values.

Superimposed on Figure 3 is a graph displaying the daily frequency of hailstorms in western Switzerland, and these frequencies are expressed as 5-day

TABLE 1

DATES AND RANKS OF EVENT-PEAKS WITH PERCENTAGE VALUES WHICH EXCEED 1 AND 2 STANDARD DEVIATIONS

Thunder Days		Hail Days		Heavy Rain Days		Tornado Days		Lightning Days	
Date	Rank	Date	Rank	Date	Rank	Date	Rank	Date	Rank
3/6*	1	3/7*	3	3/6*	2	3/6	8	3/6	6
3/19	10	3/19	12	3/26	11	3/27	9	3/13	4
3/26	9	3/26	10	4/1	13	4/19	5		
3/31*	4-	4/27	13	5/2*	5	4/28	11	4/1*	1
4/20	7	5/9	7	5/27	9	5/10	12	4/19	7
5/10	13	5/25	11	6/12	8	6/13	7	5/2	5
6/12	8	6/13	9	7/21*	1	7/12*	1		
8/29*	5	7/11	8	8/3*	3	8/4	6	6/24	10
9/11	11	8/27	6	9/14*	7	8/15	13	7/11	9
9/23	6	9/9*	1	9/27	10	8/29*	3	8/28	11
10/5	.12	9/21*	4	10/11*	6	9/15*	2	9/14*	3
10/12*	3	10/12*	2	10/18*	4	9/26*	4	9/26	8
10/26*	2	10/22	5	10/27	12	10/10	10	10/12*	2

Note:
* All peaks listed are those which exceeded one standard deviation, whereas those with an asterisk exceeded two standard deviations.

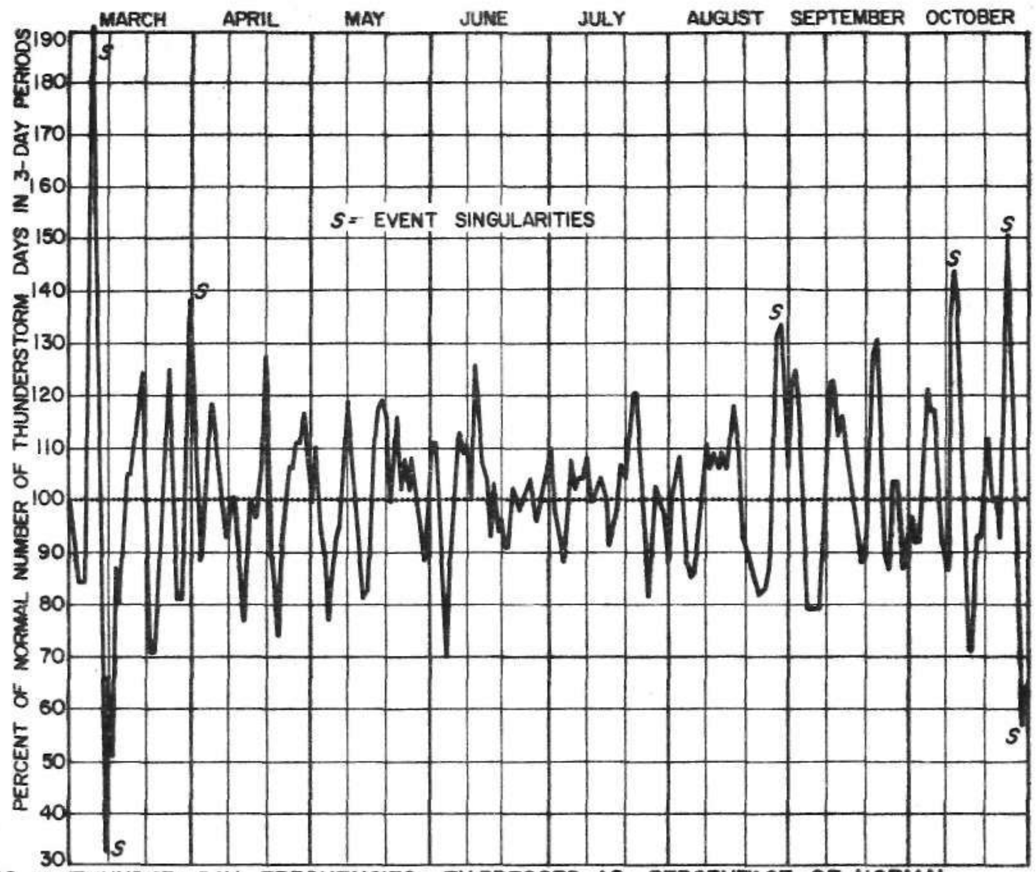

FIG. 2 THUNDER DAY FREQUENCIES EXPRESSED AS PERCENTAGE OF NORMAL

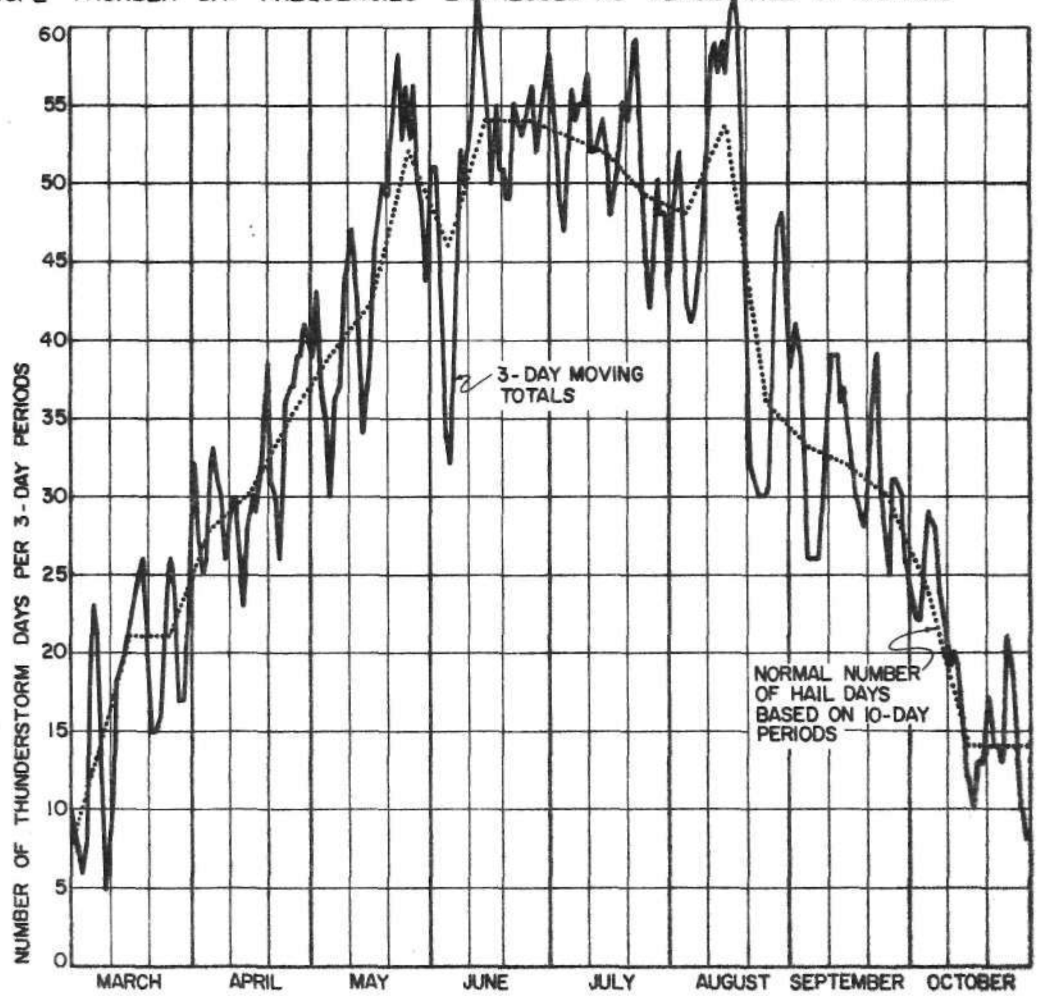

FIG. I DAILY FREQUENCIES OF THUNDERSTORM DAYS IN ILLINOIS

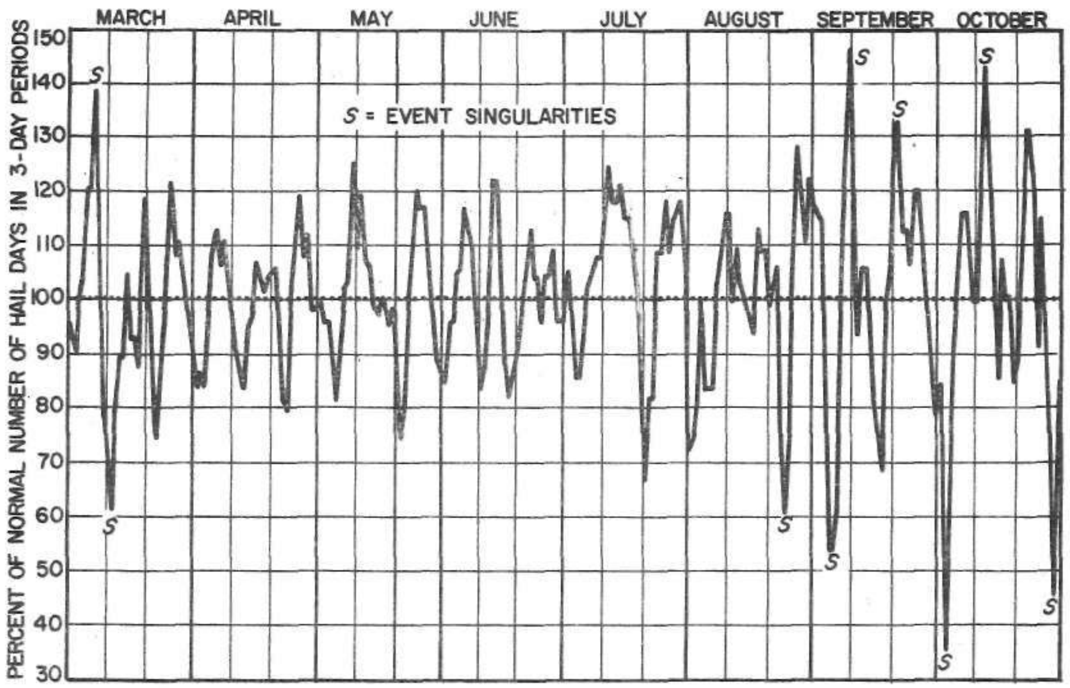

FIG. 4 HAIL DAY FREQUENCIES EXPRESSED AS PERCENTAGE OF NORMAL

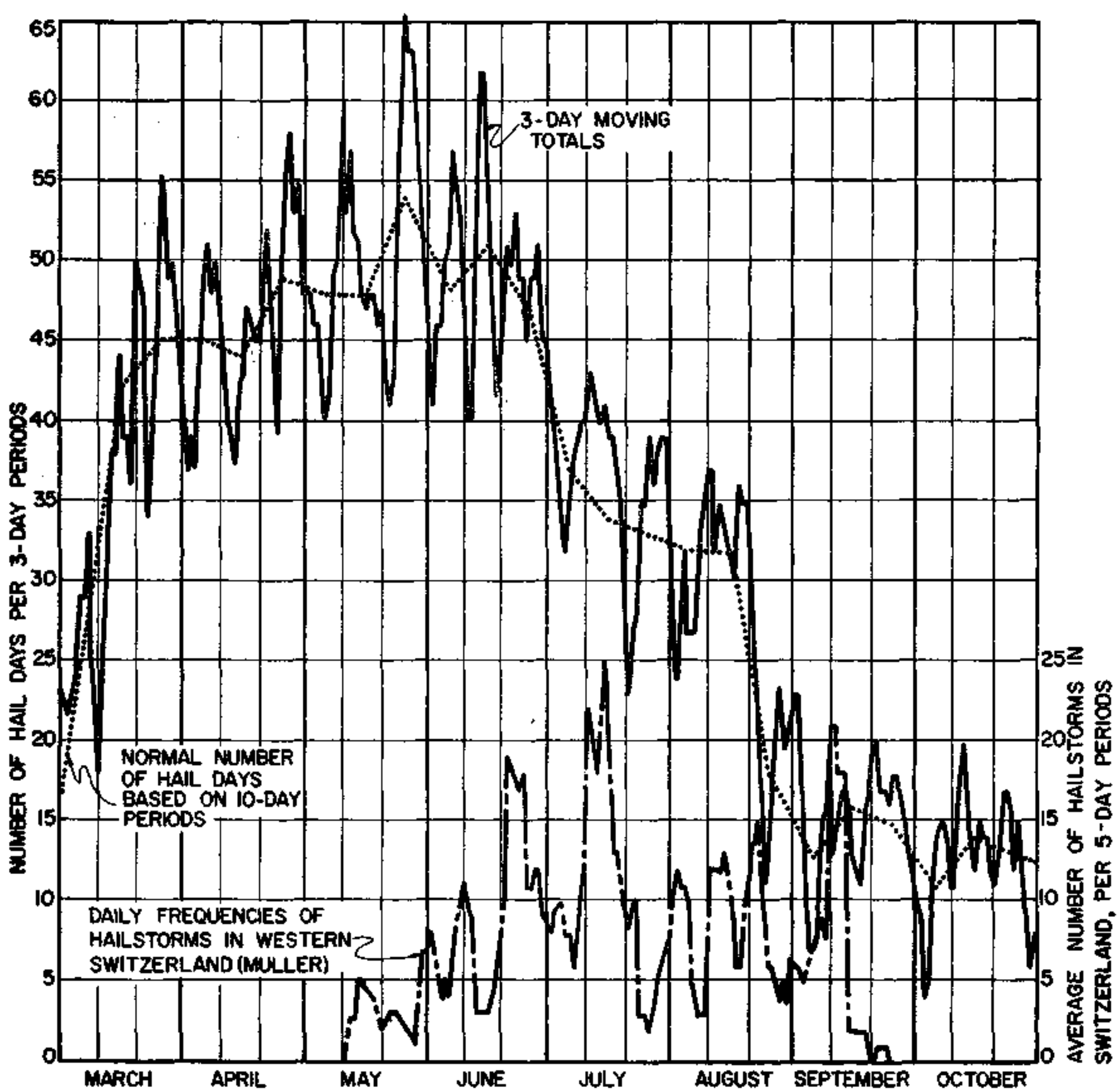

FIG. 3 DAILY FREQUENCIES OF HAIL DAYS IN ILLINOIS

moving averages. (9) A comparison of the peaks of the Swiss data with those from the Illinois data reveals a lack of association which can not be explained by mathematical differences deriving from 3-day and 5-day moving values employed. The dates of the peaks in Illinois generally occurred between the peaks of occurrence in Switzerland. There is some agreement shown by the peaks in mid-July and mid-September. However, it appears that hail singularities may not show the world-wide agreement found by Brier (4) for rainfall singularities.

The 3-day moving totals of hail days were expressed as percentages of normal and the ensuing data are plotted on Figure 4. Listed in Table 1 are the thirteen peaks which exceeded 118 percent of normal and the thirteen troughs which were all less than 84 percent of normal are listed in Table 2. These peaks and troughs exceeded one standard deviation. Also indicated in Table 1 are four peaks which had values exceeding two standard deviations. These were defined as singularities and are so marked in Figure 4. Five of the troughs listed in Table 2 had values of more than two standard deviations and these also were identified as singularities (Fig. 4).

<u>Heavy Rainfall Days</u>. The daily distribution of days experiencing heavy rainfall is displayed in Figure 5. The curve of the normal daily frequencies reveals that this event increases on an irregular basis during the spring. The peak of activity occurs in late June and again in mid-August, and the frequency gradually decreases during September and October. The single date with the greatest number of heavy rainfall occurrences was August 2 with ten in the 47-year period studies. The annual cycle of the heavy rain days, as defined by 10-day normals, is more irregular than those for thunder (Fig. 1) and hail (Fig. 3). The day-to-day variations in the percent of normal number of heavy rain days shown in Figure 6 also are greater than those for thunder and hail. Thirteen days had peaks which were more than 149 percent of normal and thirteen days had troughs which were more than 39 percent below normal. These 26 values were those which exceeded one standard deviation. As shown in Table 1, there were seven peaks which exceeded the value of two standard deviations. These were classed as event singularities and are so indicated on Figure 6. Only one trough value (Table 2) exceeded two standard deviations and was the only trough singularity for days with heavy rainfalls.

<u>Tornado Days</u>. The daily distribution of days experiencing tornadoes is portrayed by the curve of 3-day moving totals shown in Figure 7. Because of the relatively low number of occurrences per day the normal number of tornado days per 3-day periods varies from less than 1 day up to 5 days, as shown by the normal curve in Figure 7. The frequency of tornado days increases rapidly in March, reaches its maximum in late April and gradually diminishes during June and July. A secondary maximization occurs in August.

May 9 with five tornado days in 47 years of state records had the highest number of tornado days for a single date. After the 13th of October the tornado frequency fell to zero for the remainder of the month. This period was not

TABLE 2

DATE AND RANKS OF EVENT TROUGHS WITH PERCENTAGE VALUES WHICH EXCEED ONE AND TWO STANDARD DEVIATIONS*

Thunder Days		Hail Days		Heavy Rain Days		Tornado Days		Lightning Days	
Date	Rank	Date	Rank	Date	Rank	Date	Rank	Date	Rank
3/9*	1	3/11*	5	3/9*	1	3/9	8	3/9*	3
3/22	5	3/22	9	3/22	2	3/24	6	3/22*	1
3/29	10	4/24	11	4/12	7	5/6	12	4/10*	2
4/14	7	5/5	13	5/6	3	5/24	10	4/23	5
4/23	6	5/21	10	5/22	5	6/4	5	5/5	7
5/5	8	6/17	12	7/2	10	6/17	13	5/24	8
5/14	11	7/20	6	7/18	8	7/2*	3	6/16	13
6/5	3	7/31	8	7/26	9	7/20	9	7/1	10
7/26	12	8/24*	4	8/9	11	7/26*	2	9/6	11
8/24	13	9/4*	3	8/24	13	8/9	7	9/30*	4
9/5	9	9/17	7	9/19	6	8/24	11	10/6	12
10/16	4	10/2*	1	10/15	4	9/5*	1	10/17	9
10/30*	2	10/29*	2	10/30	12	9/18	4	10/30	6

Note:
* All troughs listed are those which exceeded one standard deviation, and all troughs with values which exceeded two standard deviations are asterisked.

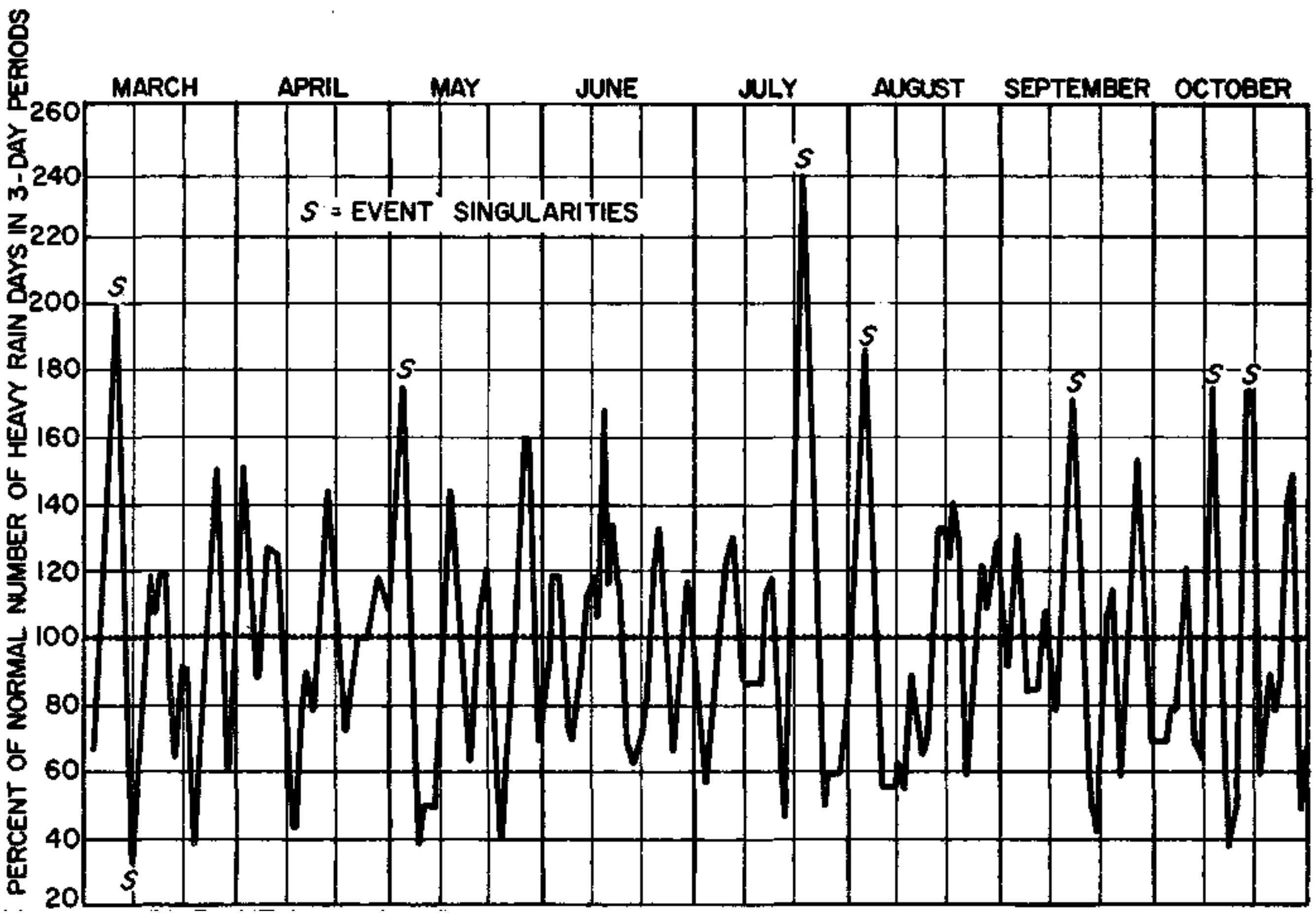

FIG. 6 HEAVY RAINFALL DAY FREQUENCIES EXPRESSED AS PERCENT OF NORMAL

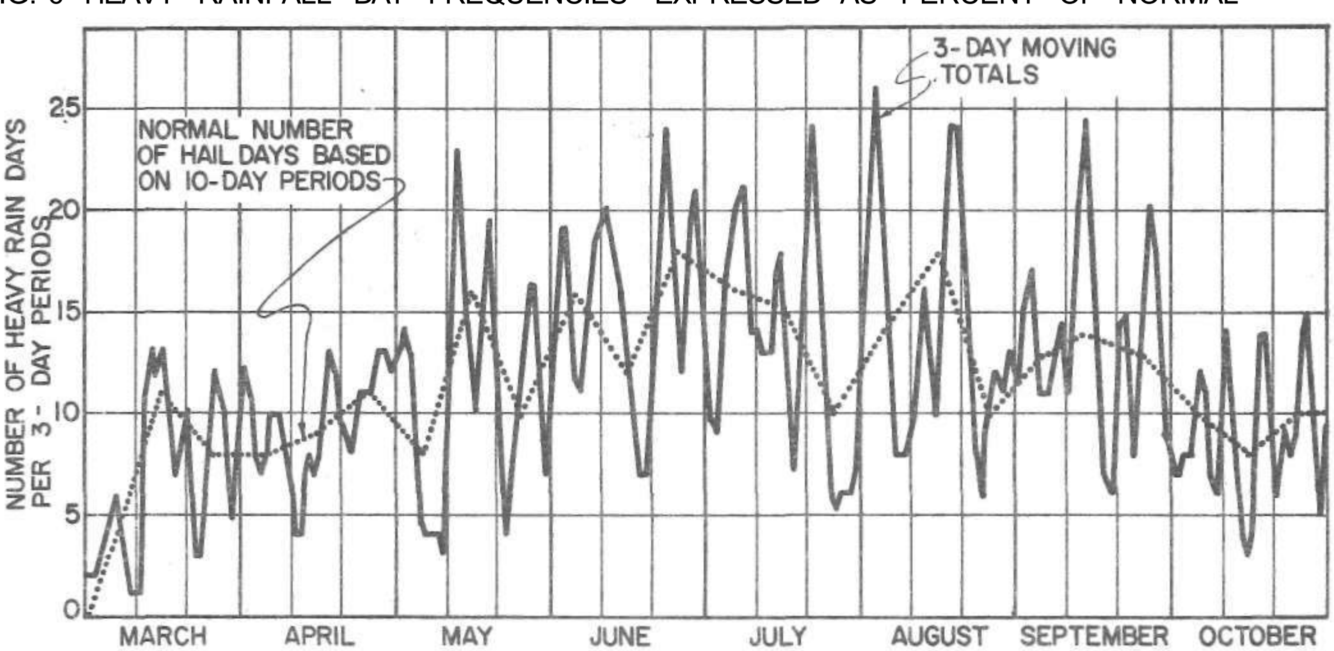

FIG. 5 DAILY FREQUENCIES OF HEAVY RAINFALL DAYS IN ILLINOIS

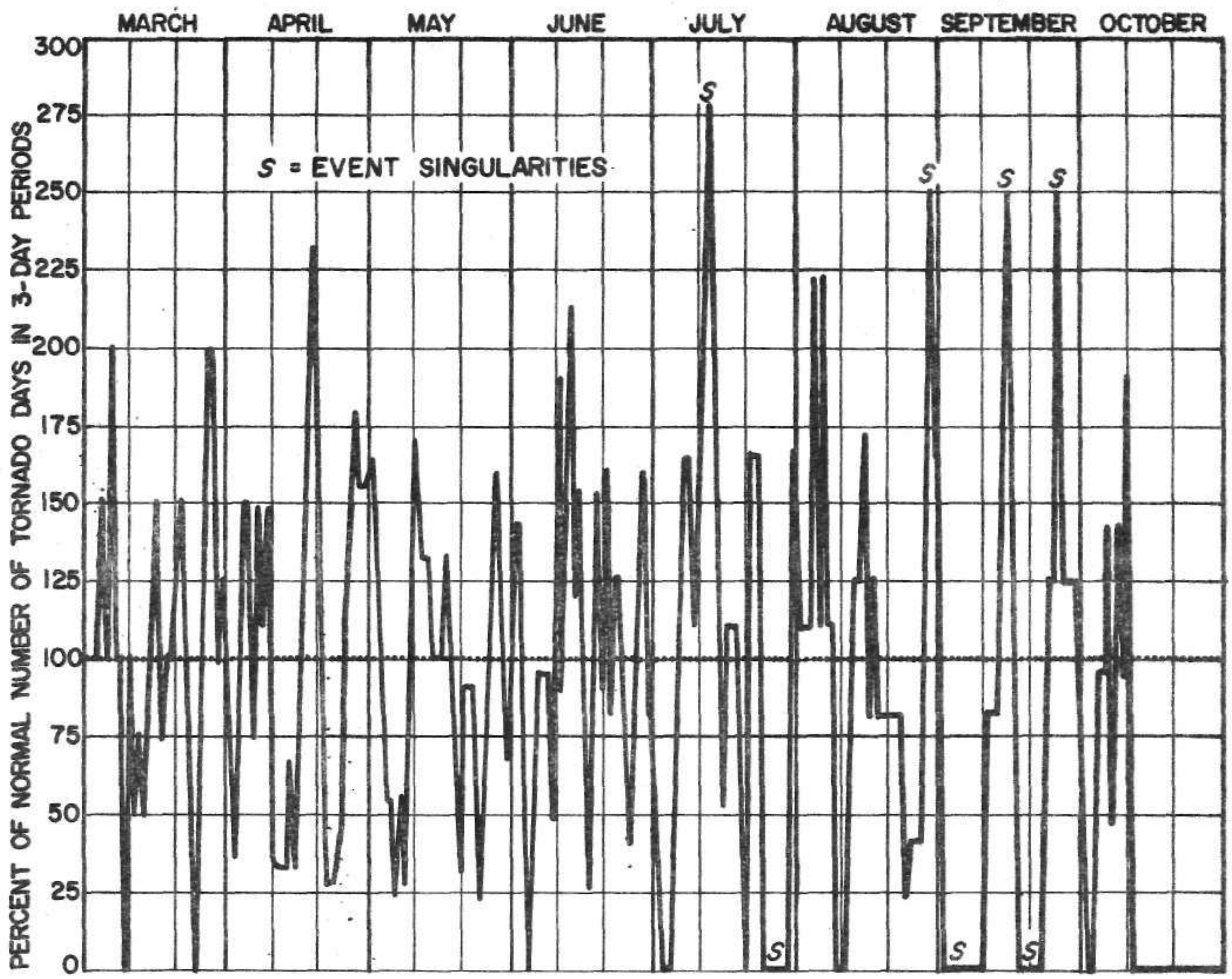

FIG 8 TORNADO DAY FREQUENCIES EXPRESSED PERCENT OF NORMAL

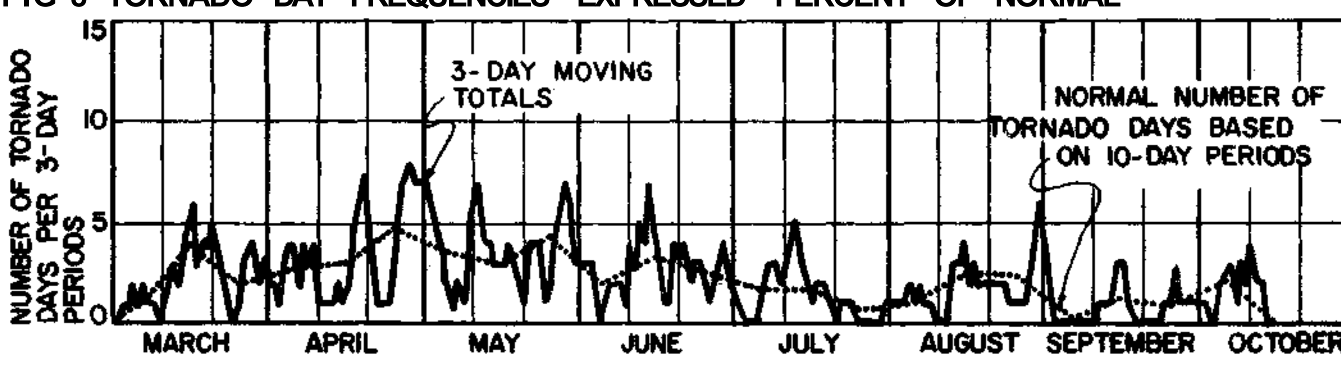

FIG. 7 DAILY FREQUENCIES OF TORNADO DAYS IN ILLINOIS

considered to be a trough because no ensuing rise occurred to define it. The 3-day moving totals are shown expressed as percentages of normal in Figure 8. Within the March 1-October 13 period, 13 peaks and 13 troughs had percentage values of more than 68 percent above or below normal, which was the value of one standard deviation. These 13 peaks and 13 troughs are listed in Tables 1 and 2, respectively. As shown in Table 1, four of the peak values exceeded two standard deviations. These four were identified as tornado singularities and are so marked on Figure 8.

Nine of the troughs listed in Table 2 had zero percentage values. These were differentiated and then ranked by counting either the number of zero daily values in their trough period or by computing a 3-day score if one or both adjacent dates had values other than 0 percent. For instance, September 5 was selected as the rank 1 trough because it was the mid-date in the longest period of days with zero values. July 26 was second ranked occurring in a period of six days with zero values. Because the lower limit of percentage values, zero percent, could not exceed the value of two standard deviations, the selection of trough singularities based upon this definition was impossible. However, the three highest ranked troughs were arbitrarily selected and identified as singularities, and these are shown in Figure 8.

Lightning Days. The daily distribution of days with damaging lightning in Illinois is portrayed in Figure 9 using 3-day moving totals. The normal number of lightning days in 3-day periods varies from about one day to twelve days as shown in Figure 9. The normal curve in Figure 9 reveals that the number of damaging lightning days increases gradually during the spring months and reaches a maximum in late July. August 8 with seven damaging lightning day occurrences in the 35-year period of record had the greatest number recorded for a single date. The normal distribution diminishes rapidly in August and September, and levels off at a relatively low frequency in October.

The 3-day moving totals of daily occurrences were expressed as percentages of normal and are shown in Figure 10. Eleven of the peak values were 158 percent of normal or greater and these exceeded the standard deviation. The dates of these peaks are listed in Table 1. Thirteen of the troughs were more than 57 percent below normal, thus exceeding one standard deviation. These troughs are listed in Table 2. As shown in Table 1 there were three peak daily values which exceeded two standard deviations, and these were identified as event singularities (Fig. 10). Identification of trough singularities by selecting those with values in excess of two standard deviations was impossible because of the zero limitation in percentages. On an arbitrary basis the three highest ranked troughs were identified as singularities by the ranking procedure employed with the tornado day data. These three trough singularities in lightning days are indicated on Figure 10.

Thunder, Hail, and Heavy Rain Composite Singularities. Composite singularities in the peaks and troughs of occurrences were determined from the event peaks and troughs listed in Tables 1 and 2. To be classified as a thunder, hail, and heavy rain composite singularity, at least two of the three events had to record a peak or trough within a 3-day period.

Based on this definition, twelve singularity peak periods were delineated in the March-October period. A rank was determined for each composite singularity based upon a score obtained by summarizing and averaging the ranks for the individual event peaks listed in Table 1. As noted in Table 3, there were four singularities with all three events reaching a peak and these were assigned ranks 1 through 4 by comparing their scores. The remaining eight singularities were given ranks 5 through 12 by sorting according to their scores, and the results are shownin Table 3. No singularity peaks were recorded in July, but March had four and September and October had two each.

TABLE 3

PROMINENT COMPOSITE SINGULARITIES BASED UPON THUNDER, HAIL, AND HEAVY RAIN PEAKS AND TROUGHS

Singularity Peat			Singularity Troughs		
Rank	Date	Events*	Rank	Date	Events*
1	3/6-7	T, H, HR	1	3/9-H	T, H, HR
2	10/11-12	T, H, HR	2	10/29-30	T, H, HR
3	6/12-13	T, H, HR	3	3/22	T, H, HR
4	3/26	T,H, HR	4-	5/5-6	T, H, HR
5	9/21-23	T, H	5	8/24	T, H, HR
6	8/27-29	T,H	6	10/15-16	T, HR
7	9/9-11	T,H	7	9/4-5	T, H
8	10/26-27	T,HR	8	9/17-19	H, HR
9	3/31-4/1	T,HR	9	4/12-14	T, HR
10	5/9-10	T,H	10	7/18-20	H, HR
11	5/25-27	H, HR	1.1	5/21-22	H, HR
12	3/19	T, H	12	4/23-24	T, H
			13	7/26	T, HR

*Event symbols are: T=thunder, H=hail, and HR= heavy rain

Similar anaylsis for the trough singularities revealed that 13 composite singularities based on the thunder, hail and heavy rain trough data in Table 2 were discernible. These composite singularities are listed in Table 3. Five of these singularities were based upon a trough of all three events within a. 3-day period. The highest ranked of these occurred in the March 9-11 period which closely followed the highest ranked peak singularity on. March 6-7.

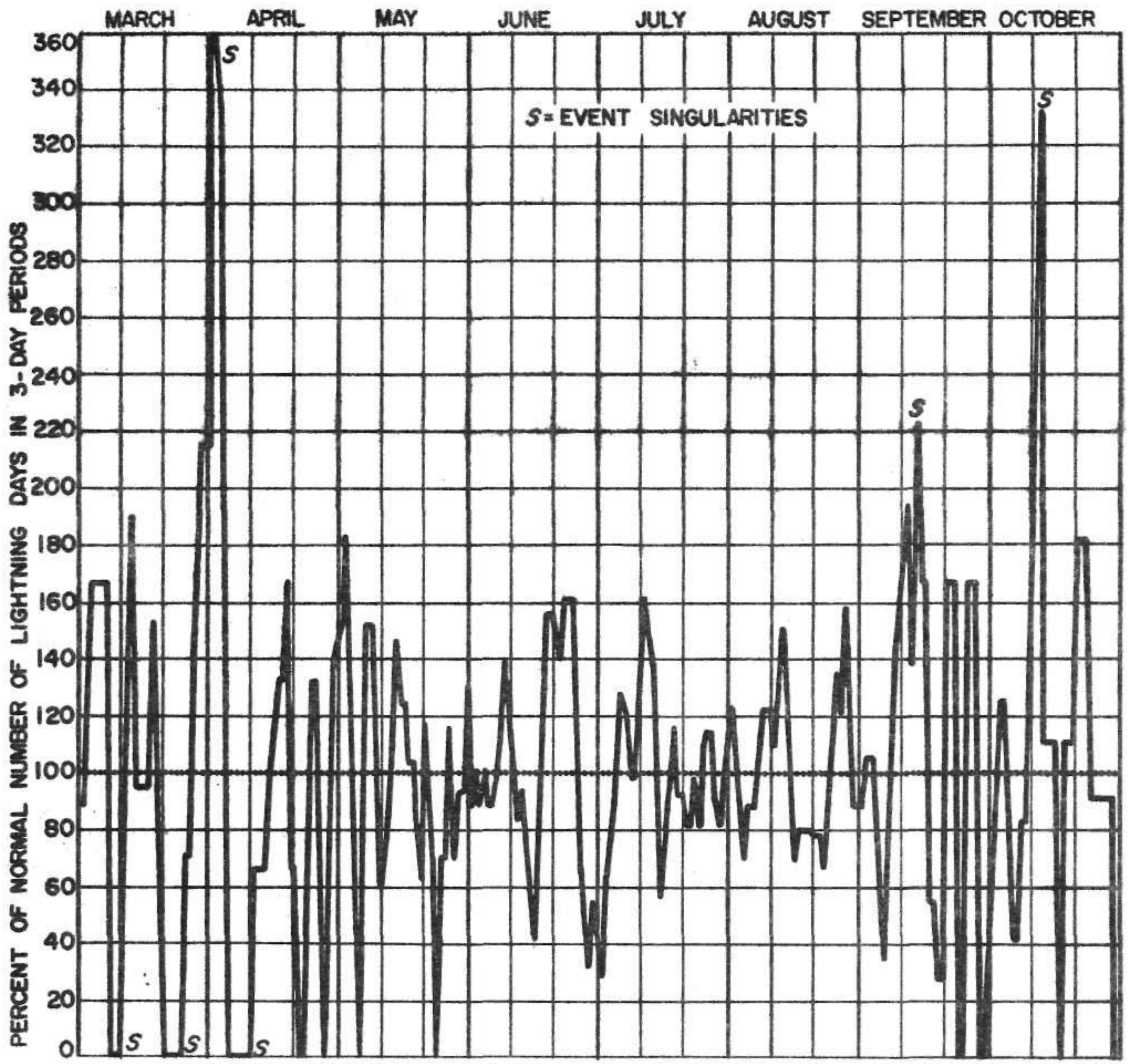

FIG. 10 LIGHTNING DAY FREQUENCIES EXPRESSED AS PERCENT OF NORMAL

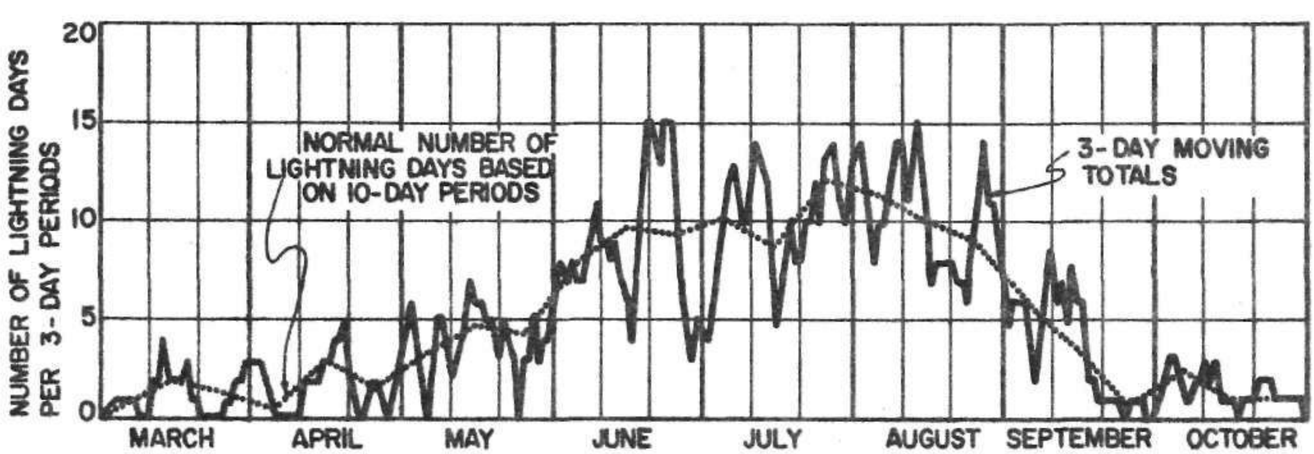

FIG. 9 DAILY FREQUENCIES OF DAYS WITH DAMAGING LIGHTNING IN ILLINOIS

Singularity Identification by Temporal Alignment of Peaks and Troughs. Comparison of the 13 troughs with the 12 peaks determined from the 3-event composite anaylsis revealed that with 8 of the peaks, a trough period occurred within 5 days or less of the peak period. The first two peak singularities in March and the two in October were followed by a singularity trough occurring 3 to 4 days later than the dates of the peak. However, the peaks in May, August, and September were all preceded by troughs which occurred from 3 to 5 days before the peak dates. Based upon such a comparison, another definition of singularity was developed because significance is added to the peaks and troughs when they are closely aligned in time. By this definition, to be identified as a singularity peak or trough, an event trough period and a peak period had to occur within a 7-day period. Based upon such a definition, eight such singularities were present in the March-October period. These were rated by comparing their summated ranks listed in Table 3. In chronological order these eight peak-trough periods with their ranks in parenthesis are: March 6-11 (1), March 19-22 (7), May 5-10 (6), May 22-27 (8), August 24-29 (4), September 17-23 (5), October 11-16 (2), and October 26-30 (3). These closely related peaks and troughs suggest that great surges and recessions in the factors producing severe weather occur in very short periods of time and on the same calendar dates in many years.

Statistical Testing of 3-event Composite Singularities. The reality of the 3-event composite singularities was tested using a statistical method employed by Brier (4) to test the reality of rainfall singularities. Brier's method of testing was designed to be largely unaffected by any persistence in the auto-correlation relationships brought about by using moving-day values and by similarity in the nature of the events being compared. For each event the 13 dates of peaks along with their preceding day and following day were assigned values of 1, producing a total of 39 days with 1 values. Similarly, the 13 trough days and their adjacent days were assigned -1 values of which there were 39. The remaining 167 days were assigned values of 0. This was performed for thunder, hail, and heavy rain. The resulting distributions were compared on a calendar day basis and the measure of association between the three time series was determined by counting the number of times the following combination of events occurred.

a. Daily occurrence of three 1 values.
b. Daily occurrence of three -1 values.
c. Daily occurrence of three 0 values.
d. Daily occurrence of two 1 values and a 0 value.
e. Daily occurrence of two -1 values and a 0 value.

By counting all cases of a, b, c, d, and e, as "hits", a score of 156 was obtained for the 245-day period. The frequency of the 1, 0, and -1 values in the three series is such that the expected score would be 105 hits if they were independent.

The significance of the 156 score was examined by determining the scores that could occur by displacing the series relative to one another. The thunder data were considered the base or control data and the hail and heavy rain data were displaced relative to the thunder data. In Table 4 the scores obtained with displacements of up to 5 days are shown. The hail data and heavy rain data each were displaced up to 15 days resulting in the computation of 961 scores, of which only 3 were 156 of greater. This makes the score of i56 significant at the $\frac{4}{961} = 0.00417$ probability level.

The highest score found in the 961 cases was the 163 shown in Table 4 for a hail displacement of 1 day and 0 displacement in heavy rain days. If the high score had occurred in any one of the other five possible positions one day from the actual day, which are marked by asterisks in Table 4, the high score would have been just as significant. Therefore, the -statistical significance of the location of highest score is $P = \frac{7}{961} = 0.00728$. Obviously, the 13 peaks and 13 troughs are significant events and could be classed as related composite singularities.

The degree to which this relationship is phased with the calendar date was examined by computing the average score when the series were displaced from each other by 0 day, 1 day, 2 days, etc. (4) The 0 day score is 156. The average score for a displacement of one day is computed from the six values with asterisks in Table 4. The resulting average score for 1 day displacement was 148, and this value and the other displacement values are depicted in Figure 11. The abscissa is expressed as one-half of the total displacement since the total displacement of the 2-day category could represent a maximum separation between hail (+2 days) and heavy rain (-2 days) of 4 days when the deviation to either from the mid-point would be only 2 days. The curve in Figure 11 shows that the relationship of these events with the calendar date diminishes rapidly as the two series are displaced relative to each other. Apparently the atmospheric conditions which cause severe weather in Illinois have sharp temporal impulses on or about certain calendar dates in order to cause the high degree of calendar day association revealed by the agreement between severe weather singularities.

An argument offered when significance is denoted in the statistical tests for the composite singularities is that it may be a false significance because these events may be auto-correlated. That is, severe weather events frequently occur together resulting in similar singularities, and a high statistical expression of significance would be expected to occur. However, the high degree of significance actually attained from the tests of reality for these singularities is quite meaningful because of the known physical correlation between these events. Since the events are all related to thunderstorms and phases representing their intensification, any findings which indicated dissimilar dates for singularities among the events would indicate inadequate sampling and a lack of reality in the singularities.

Five-Event Composite Singularities. Composite peak and trough singularities were determined from the data on thunder, hail, heavy rain, lightning, and tornado days listed in Tables 1 and 2. In Figure 12 a schematic drawing depicting the dis-

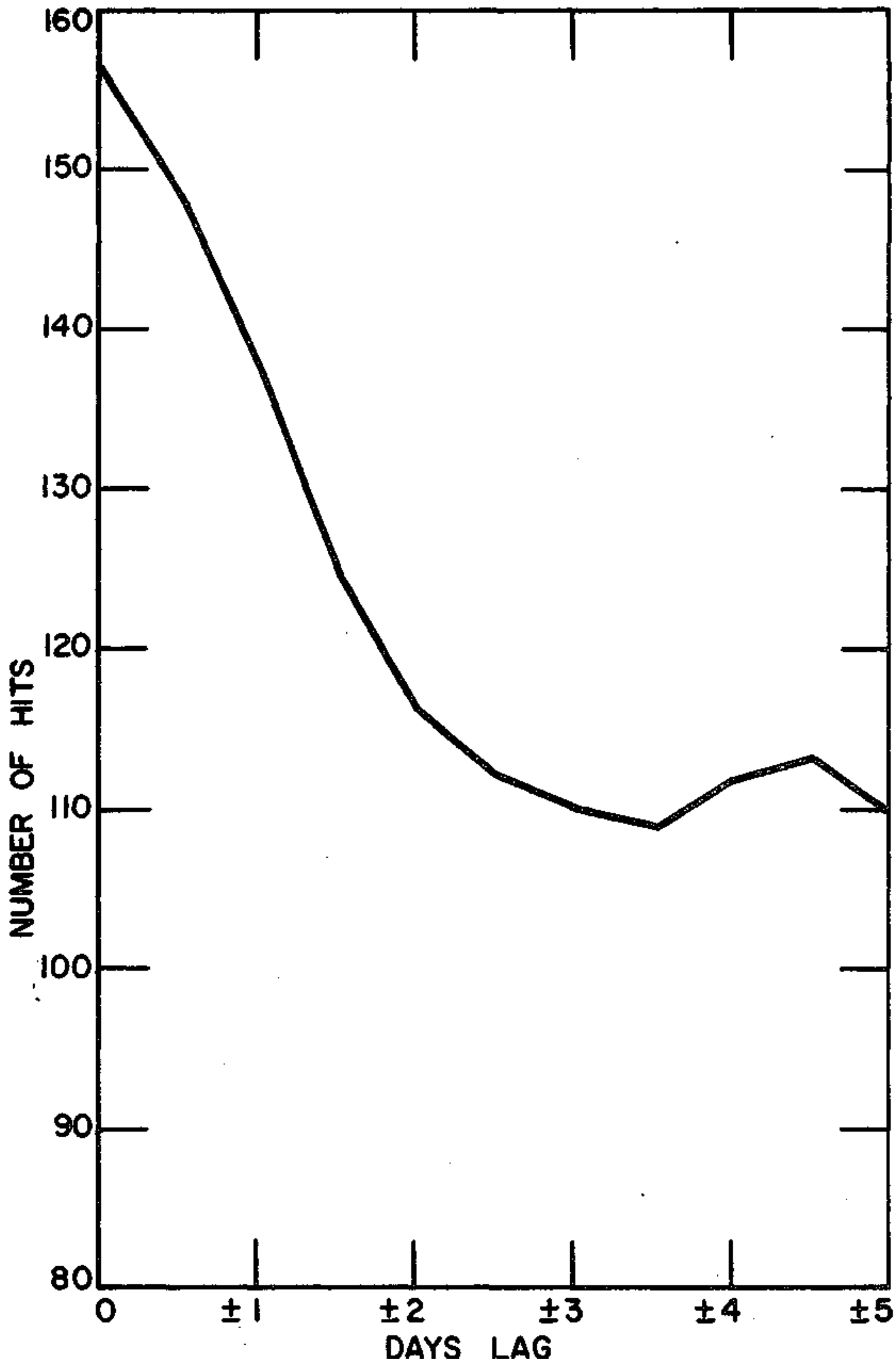

FIG. 11 AVERAGE NUMBER OF HITS ACCORDING TO MEAN DISPLACEMENT OF HAIL AND HEAVY RAIN SERIES FROM CENTRAL DAY OF THUNDER SERIES

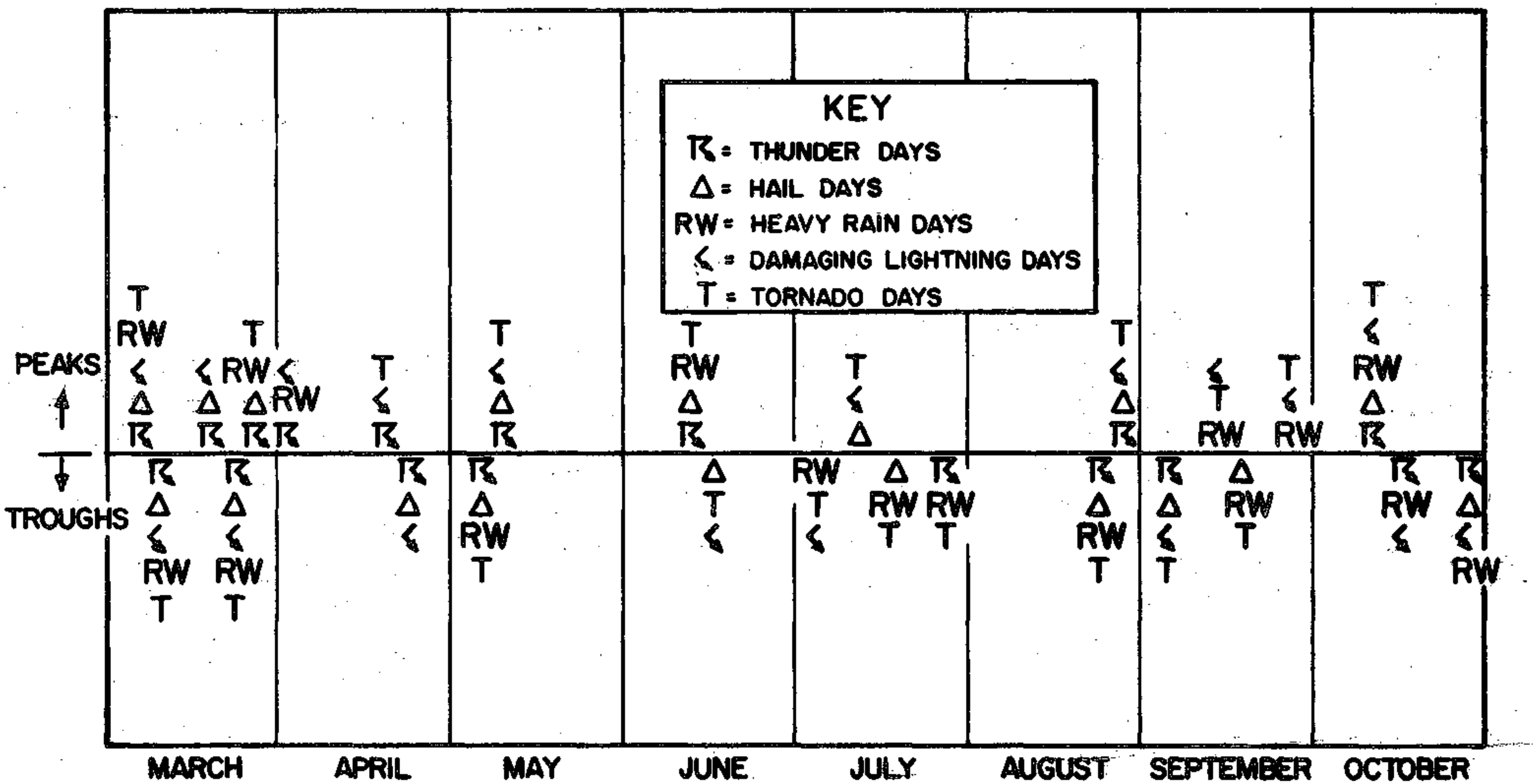

FIG. 12 SCHEMATIC PORTRAYAL OF PEAKS AND TROUGHS

TABLE 4

NUMBER OF HITS ACCORDING TO VARIOUS COMBINATIONS OF DAILY DISPLACEMENT LAGS FOR HAIL DAYS AND HEAVY RAIN DAYS

Hail Days

		-5	-4	-3	-2	-1	0	1	2	3	4	5
	-5	117	111	104	108	120	129	125	112	98	94	96
	-4	115	111	108	109	120	125	118	108	99	94	91
	-3	105	108	109	116	127	128	119	106	100	101	95
	-2	107	111	114	118	135	143	135	116	107	109	114
	-1	109	114	120	124	135	153	153	132	117	115	125
Heavy	0	120	117	123	130	143	156	163	151	134	127	130
Rain	1	107	105	113	126	135	145	151	150	135	123	119
Days	2	94	92	98	114	130	136	140	138	129	115	108
	3	83	84	89	103	119	131	127	122	111	103	98
	4	82	80	88	99	123	130	129	116	109	102	98
	5	82	79	84	104	124	139	125	115	106	107	100

tribution of peaks and troughs composed of three or more events is presented. To be classified as a 5-event composite singularity, 4 or more of the 5 events had to achieve a peak or trough within a 3-day period.

Based on this selection level, singularity peaks were ascertained in the March-October period, and these are listed in Table 5. The composite singularities with 5 events occurring together were ranked higher than those with 4 events. Within the two possible singularity levels, as based upon 5 or 4 events, ranks Were assigned as determined upon a score determined from the individual event ranks listed in Tables 1 and 2. For instance, the four events comprising the August 27-29 peak singularity had a total rank score of 25, whereas the 4-event score on June 12-13 was 32. Thus, for the four -4-event level of peak singularities, the August 27-29 peak was ranked higher than the June 12-13. As noted in Table 5 there were six singularity troughs in which four or five of the events recorded troughs. These were ranked in the same manner as that used for the singularity peaks.

The reality of composite singularityies among the five events was tested using the same method employed for testing the 3-event singularities. For each event, the dates and adjacent days for the 13 peaks were assigned a value of 1; the dates and adjacent days for the 13 troughs were assigned -1 values, and the remaining 167 days were assigned a 0 value. A "hit" for a given date was counted when 1) all five event values were 1, 2) all were -1, 3) all were 0, 4) four were 1 and the fifth event was 0, 5) four were -1 and the fifth was 0, 6) three were 1 and two were 0, and 7) three were -1 and two were 0. The frequency of the three values in the five series is such that the expected score would be 46 hits if the series were independent. Tha actual score of number of hits was 131 which is almost three times the number expected by change.

TABLE 5

COMPOSITE SINGULARITIES BASED UPON PEAKS AND TROUGHS OF FIVE EVENTS

Singularity Peaks			Singularity Troughs		
Rank	Date	Number of Events	Rank	Date	Number of Events
1	3/6-7	5	1	3/9-11	5
2	10/10-12	5	2	3/22-24	5
3	8/27-29	4	3	5/5-6	5
4	6/12-13	4	4	10/29-30	4
5	3/26-27	4	5'	9/4-6	4
6	5/8-10	4	6	8/24	4

<u>Selection of Singularities by Comparison. As stated</u> in the earlier portion of this paper, there are many ways to identify and define singularities. A few of these have been employed to identify singularity peaks and troughs in the frequencies severe weather events in Illinois. Among the singularities defined were those for the individual events, the two groups of composite singularities, and the time-related peak and trough singularities. The question still remains: Which of these are singularities?

In an effort to answer this question, all peak singularities identified by the five individual events, the two composite schemes, and the time-aligned peak-trough procedure were listed and compared. All 3-day periods in which at least four of the eight possible criteria recorded a, singularity were selected as comparative singularities.

There were three peak singularities which met this requirement. The October 10-12 peak in severe weather activity was listed as a singularity by seven of the eight criteria. Only for tornado days did this 2-day period fail to be judged as a singularity peak. The March 6-7 period was identified as a peak by six of the eight possible criteria. Only the tornado and lightning data failed to record this 2-day period as a peak singularity. The third singularity peak identified by this final procedure was the August 27-29 period with four of the eight criteria listing it as a peak singularity. None of the individual events except thunder identified this period as a singularity.

There were four trough singularity periods in which four or more of the eight criteria identified a trough. The March 9-11 period was listed as a singularity trough by seven of the identification procedures. Only the tornado data failed to identify this 3-day period as a singularity trough. The October 29-30 period was identified as a singularity trough by five criteria. The March 22-24 period and August 24 each had four criteria listing them as singularity troughs, Thus, this comparative selection method resulted in a total of seven singularities for severe weather.

<u>Possible Causes for Singularities in Severe Weather.</u> Another question remains: If these severe weather singularities are real, what are their causes? If other meteorological parameters and conditions have similar singularities, possibly some explanations can be offered to this question. If correlative realtionships exist between severe weather events and other related weather conditions, these would help to substantiate the claims for reality of severe weather singularities as well as to help explain their occurrence.

To this end, certain available weather data which would serve in some degree as indicators of the general condition and stability of the atmosphere in Illinois were analyzed to obtain their daily frequencies. Maximum temperature data were analyzed because it serves as a relative measure of the stability and air mass type present at the approximate time when severe weather begins most frequently. (LO) Relative humidity was the only data readily available which could serve as an indication of the moisture content of the atmosphere. Pressure is indicative of the general stability conditions and sunshine data indicate the degree of cloudiness. From the daily values of these four conditions,, 3-day moving averages and normals were computed and the resulting time series graphs are shown in. Figures 13-16. Several peaks and troughs are apparent in each series.

The twelve singularities indicated by the 5-event composite method were compared with the climatological data shown in. Figures 13-16. The 3-day moving averages were evaluated by comparing the position of their curves with the normal curves on the dates of the twelve singularities. Thus, the 3-day ayerage values could be classed as being in a trough, a peak, or neither a peak or trough on the dates of the singularities. The results of this evaluation are shown in Table 6. In general, the peak singularities were characterized by relatively more cloudiness (or less sunshine), low pressures, high temperatures, and high relative humidities. Thus, a combination of generally warm, moist, cloudy, and unstable conditions were found to associate with the severe weather peaks, and this combination is as expected theoretically and as desired for confirmation of their reality. The major exception occurs with the August 27-29 singularity when the pressure values have a moderate peak instead of a trough and there is a trough instead of a peak in the maximum temperature curve.

The results obtained for the trough singularities also had theoretically desired relationships between the singularities and the four weather conditions. In most instances, the troughs in severe weather activity were associated with high pressures, less cloudiness, low maximum temperatures, and low relative humidities; or occurred during periods that were relatively cool;,, dry, clear, and stable.

The close temporal relationship noted between peaks and troughs of the events and also between some of the other weather singularities listed in Table 6 suggests at least one explanation of the immediate synoptic conditions in the North American area which cause certain of these severe weather singularities in Illinois.

As noted earlier, in the spring and fall months the singularity trough followed the peak. From theoretical considerations and regard for the findings displayed in Figures 13-16, it appears that the peak-to-trough singularity relationship in the transition seasons might rep resent a synoptic condition which begins with an increasing predominance of moderately warm-moist air in Illinois. This air mass is supplanted by a rapid southward intrusion of a major cold front which brings an outbreak of severe weather with its passage, thus creating a singularity peak. The following cold air and stable conditions dominate the weather in the succeeding days allowing little or no chance for the occurrence of severe weather, and hence a singularity trough occurs.

It is apparent that the high degree of association between the singularities in severe weather and those in related weather conditions confirm the reality of the composite singularities and also serve as an indication of the synoptic situations which produce the singularities. No further explanation is offered as to why these features of the North American circulation pattern behave more or less frequently on or about certain calendar dates. This behavior is undoubtedly only a portion of abrupt impulses and changes that occur in the world-wide cir-

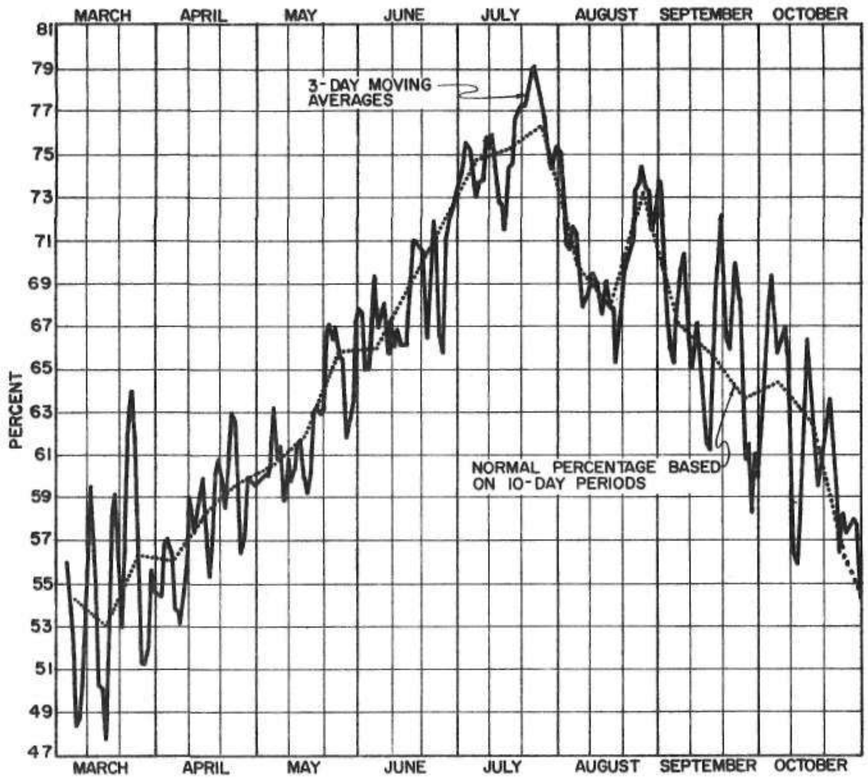

FIG. 13 AVERAGE DAILY PERCENTAGES OF POSSIBLE SUNSHINE IN ILLINOIS

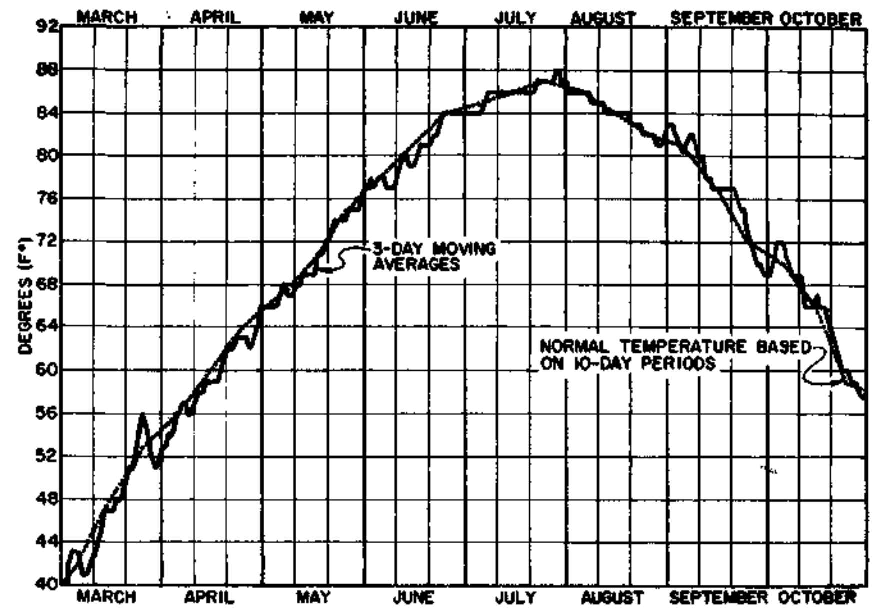

FIG. 14 AVERAGE DAILY MAXIMUM TEMPERATURE IN ILLINOIS

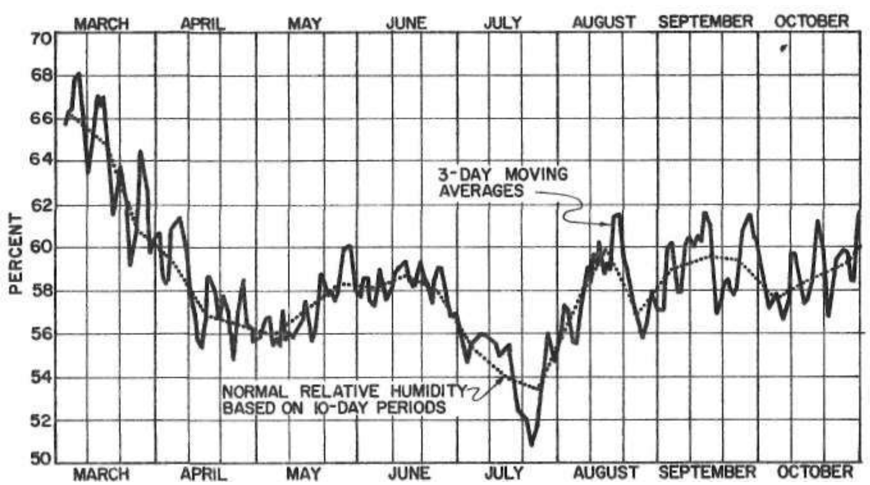

FIG. 15 AVERAGES DAILY RELATIVE HUMIDITY VALUES IN ILLINOIS

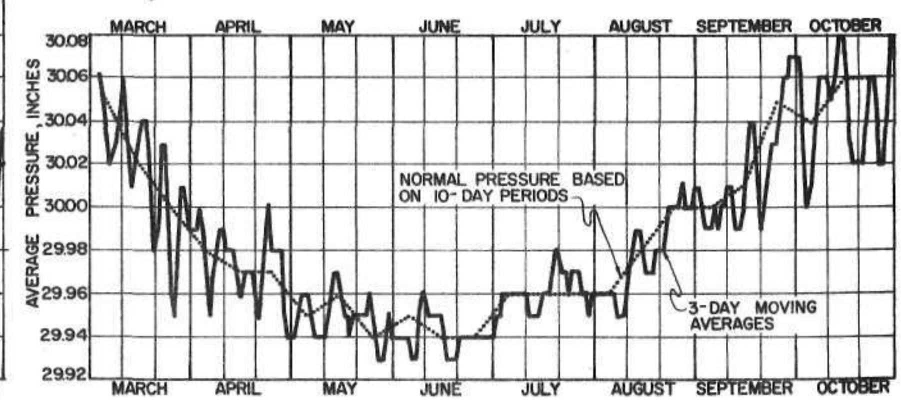

FIG. 16 AVERAGE DAILY PRESSURE (MLS) ,AT 1800 CST IN ILLINOIS

TABLE 6

DATES OF TWELVE COMPOSITE SEVERE WEATHER SINGULARITIES AND RELATED PEAKS AND TROUGHS IN TEMPERATURES, PRESSURE, HUMIDITY,: AND SUNSHINE

Singularity Peaks					Singularity Troughs				
Dates	Associated Conditions				Dates	Associated Conditions			
	Pressure	Max. Temp.	Rel. Hd.	Sun.		Pressure	Max. Temp.	Rel. Hd.	Sun.
3/6-7	T	P	P	T	3/9-11	P	T	T	P
3/26-27	T.	P	P	T	3/22-24	P	-	T	P
5/8-10	T	-	P	T	5/5-6	P	P	T	P
6/12-13	T	-	P	T	8/24	-	—	T	P
8/27-29	P	T	P	T	9/4-6	-	T	T	P
10/10-12	T	P	P	T	10/29-30	P	T	T	P

culation patterns. Possibly, these large-scale hemispherical changes in the atmosphere are related to the lunisolar cycle which has recently been shown to correlate with the occurrence of heavy rains in the United States. (11)

Summary

By using a selection level requiring event extremes in excess of two standard deviations, singularities were defined for each of five severe weather events. Comparison of these results indicated that there were 14 periods in which one or more events recorded singularity peaks and there were 9 periods when one or more events recorded a singularity trough.

One set of composite singularities were determined using the highly reliable thunder, hail, and heavy rainstorm data. Statistical testing of these events using the highest 13 peaks and the lowest 13 troughs of each event definitely indicated reality in their occurrence as singularities. Another method of identification employed in the study required occurrence of a major peak and a major trough within a 7-day period. This method identified eight periods with peak-trough or .. trough-peak singularities.

Composite singularities also were determined from the peaks and troughs of all five events and this selection method resulted in twelve singularities. All of these twelve also were identified as singularities by the individual event definition, by the 3-event composite procedure, by the time related peak-trough definition, and by the method of comparative selection. Because of this and the high degree of correlation of these twelve singularities with anomalies in related weather conditions, the singularities selected as most representative are those twelve listed as 5-event composite singularities. The comparative selection method failed to identify certain prominent singularities that achieved identification in the two composite groups and in the time-aligned peak-rtrough singularity listing.

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