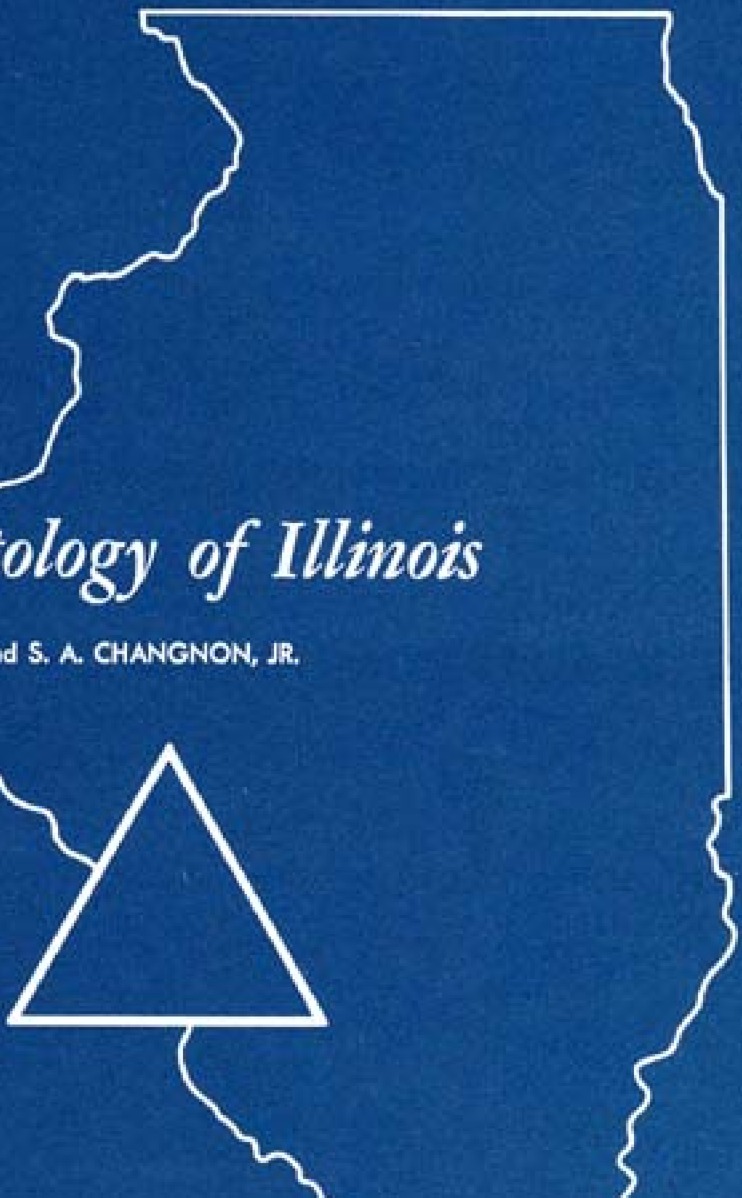
REPORT OF INVESTIGATION 38

STATE OF ILLINOIS
WILLIAM G. STRATTON, Governor

DEPARTMENT OF REGISTRATION AND EDUCATION
VERA M. BINKS, Director



Hail Climatology of Illinois

by F. A. HUFF and S. A. CHANGNON, JR.

ILLINOIS STATE WATER SURVEY
WILLIAM C. ACKERMANN, Chief

URBANA
1959

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SUMMARY AND CONCLUSIONS

Extensive examination of the records of the U. S. Weather Bureau stations in Illinois for the 1901 through 1950 period provided data for a detailed study of the hail climatology of Illinois. Methods of evaluating cooperative substation records were developed in order to obtain a sufficiently dense network of hail observation points. Records from 12 First-Order stations and 73 cooperative substations were used in the study.

In an average year the number of hail days at a point varies between one and four in Illinois. With respect to physiographic divisions, hail is most frequent in the Springfield Plain area in the west central portion of the state. Two other regions with relatively high average frequencies are located in the Shawnee Hills of southern Illinois and in the Rock River Hill Country and Wisconsin Driftless Section in the northwestern part of the state. Areas of Illinois experiencing the lowest number of hail days in an average year include a portion of the Galesburg Plain west of the Illinois River valley and most of eastern Illinois.

The number of days with hail varies considerably from year to year and from decade to decade. As many as ten hail days occurred at one station in a single year during 1901 through 1950; however, no hail days were observed over a considerable portion of the state in some years.

Statistical tests indicated that a relatively long period of observations is required at a station to obtain a reliable measure of the average frequency of days with hail. Using data for six First-Order stations of the U. S. Weather Bureau, calculations indicated that a sampling period of 20 years or longer is required to keep the average sampling error of annual hail frequency for this group of stations below 10 percent; however, at a particular station the sampling error may be as great as 20 to 30 percent in any given 20-year period.

In an average year, March through August encompasses approximately 80 percent of the annual hail days. The primary season for hail is spring, March through May. The month of most frequent hail activity varies from March through June over the state, with a general south to north trend exhibited. Following spring, hail frequency shows a continuous decrease through the summer and fall months and reaches a minimum in winter.

Approximately 90 percent of the state experiences at least one day with hail in an average year. During an average July and August, when the major Illinois crops are most susceptible to hail damage, only 25 percent of the state has one or more days with hail.

The area experiencing hail on a single day normally is greater in March and April than at any other time of the year. Hail occurrences during a day in middle or late summer are usually restricted to a relatively small area.

Most of the extensive hailstorms in Illinois occur in Spring. They are usually associated with strong synoptic weather systems which have pronounced frontal contrasts and strong winds. Heavy rainfall characterizes a majority of these storms. The 24 days having the most extensive hailstorms during the period from 1925 to 1948 occurred between March and June, and in 71 percent of these storms, more than one inch of rain fell over at least one-third of the state. In 54 percent of the storms, mean rainfall exceeded two inches over 5000 square miles, while in 42 percent of the storms the mean rainfall exceeded three inches over 1000 square miles.

Diurnally, hail in Illinois, just as tornadoes, maximizes in the afternoon with the peak three hours of activity from 2:30 P.M. to 5:30 P.M. This diurnal distribution suggests that the violent convection necessary for hail and tornado development is realized most often at the time of maximum diurnal heating. Thunderstorms occur with the greatest frequency two to three hours after hail and tornadoes, while heavy rainstorms exhibit a night maximum.

High frequencies of hail in the Rock River Hill Country-Wisconsin Driftless Section and in the Shawnee Hills Section may be related to the sharp contrasts in relief between the outcroppings and the relatively flat plains to the south and southwest of these hill regions. Elevation alone does not appear to affect significantly the frequency of hail in Illinois. A poor correlation was found between station elevation and annual hail frequency. A slight tendency for hail frequency to increase with elevation was indicated in summer, but this tendency was not sufficient to be considered statistically reliable.

ACKNOWLEDGMENTS

This report was prepared under the direction of William C. Ackermann, Chief of the Illinois State Water Survey. Research was accomplished under the general guidance of Glenn E. Stout, Head, Meteorology Section.

Within the Meteorology Section, special credit is due Dorothy Hiatt for performing much of the laborious analyses. Several other research assistants aided in the tabulation and routine analysis of data, and Raymond Pittman did the drafting.

Data which made this study possible were obtained from climatological records compiled by the U. S. Weather Bureau at their First-Order and cooperative stations.

INTRODUCTION

The purpose of this study is to provide a climatological description of hailstorms in Illinois. The study was undertaken as part of the general program of the Meteorology Section of the State Water Survey, which is directed toward obtaining a greater understanding and knowledge of the precipitation processes and their behavior in Illinois. A related study, not reported here, is being conducted under contract with the Crop-Hail Actuarial Association to investigate past and present Illinois hailstorms by correlating crop hail damage with radar data and surface and upper air weather maps.(1)

The present report is devoted primarily to presentation of extensive statistical analyses of the daily, monthly, seasonal, and annual distribution of hail in the state. However, some consideration has been given to physical factors affecting hail distribution and to the association of rainfall and other synoptic weather features with hailstorms.

DESCRIPTION OF DATA

In undertaking the hail study, the authors were faced with much the same type of data problems encountered in an earlier report. (2) Hailstorms and thunderstorms are weather phenomena of relatively small areal extent which exist in one location for only a limited period, usually only a few minutes. Therefore, a major problem encountered was to obtain a network of observation stations which would represent adequately the areal and seasonal variations of hail occurrences. This problem was solved largely by using data from U. S. Weather Bureau cooperative substations in the state in conjunction with data from the First-Order stations in and near Illinois. However, the inclusion of the cooperative substation data led to another major problem. The reliability of substation records is questionable because the number of days with hail, thunderstorms, and other elements is reported merely on a "yes" or "no" basis. Reliability of these "days with" records varies considerably depending on the interest and qualifications of volunteer observers who maintain the cooperative substations. Several methods of evaluation were applied to the cooperative substation data in order to make it usable in this study.

The period selected for the hail study was the 50 years extending from 1901 through 1950. During most of this period, data were available from five First-Order stations in Illinois. In addition, seven First-Order stations just outside the state boundaries had data for all or portions of this 50-year period. The twelve First-Order stations and their periods of record used in this study are shown in Table 1. Because these First-Order stations are operated by technical personnel of the U. S. Weather Bureau, the data are considered reliable and served as the analytical basis of reference for the entire study.

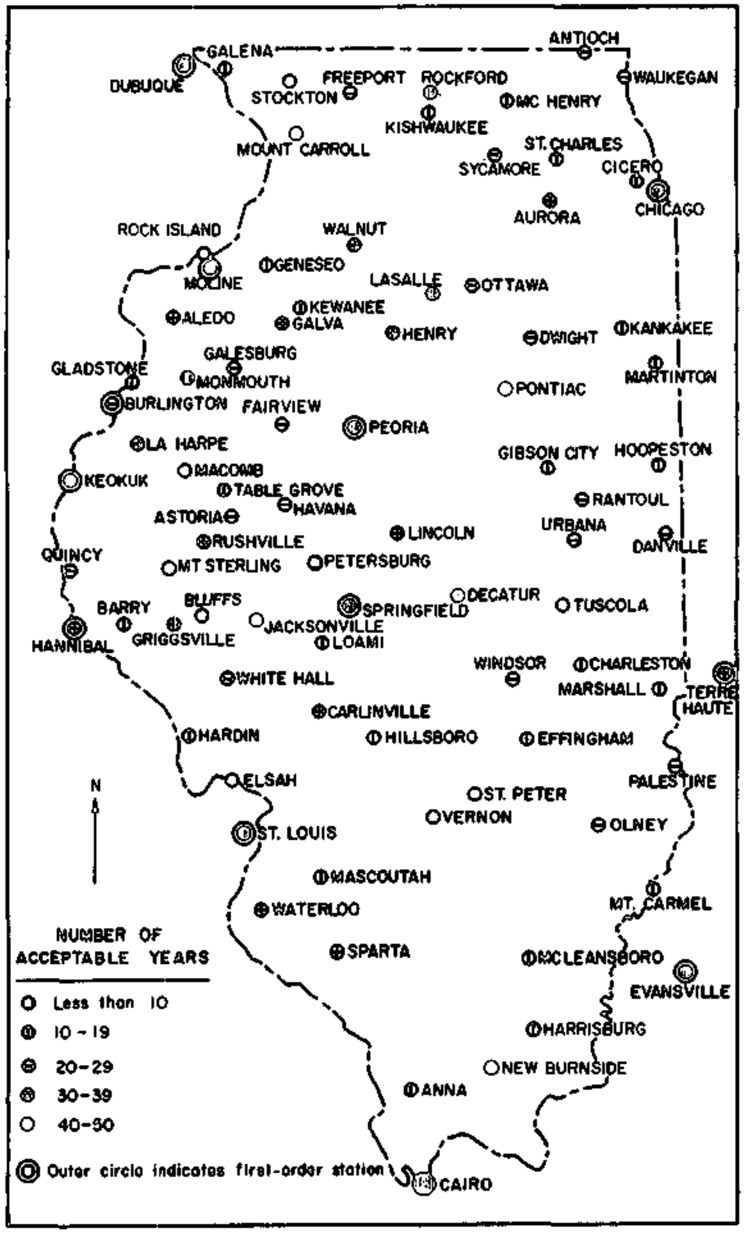
TABLE 1

FIRST-ORDER STATION HAIL DATA DURING THE PERIOD 1901 THROUGH 1950

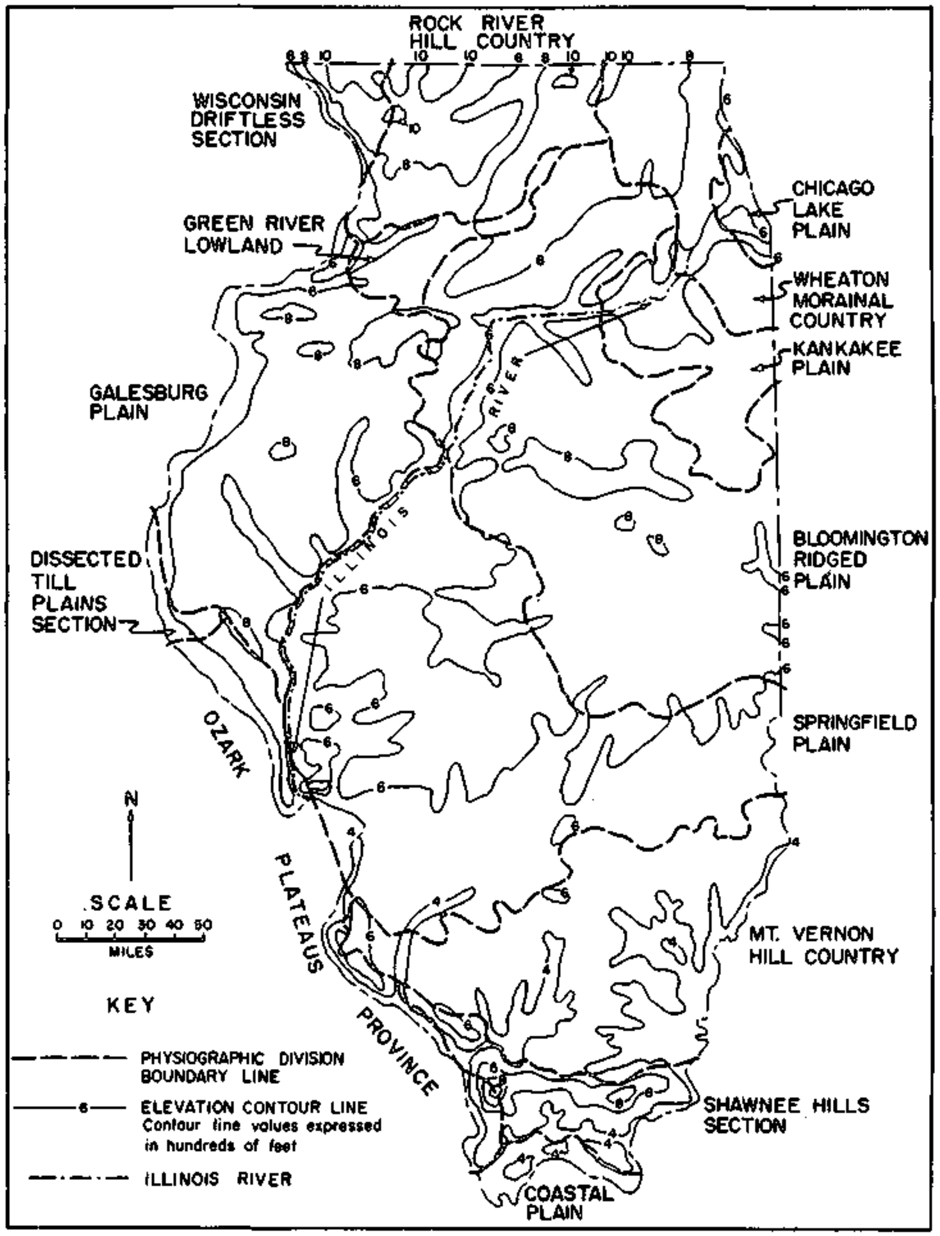
	Period of Record	Total Years
Burlington, Iowa[1]	1942-1950	9
Cairo, Illinois	1904-1950	47
Chicago, Illinois	1901-1950	50
Dubuque, Iowa	1901-1950	50
Evansville, Indiana	1901-1950	50
Hannibal, Missouri	1901-1932	32
Keokuk, Iowa	1901-1946	46
Moline, Illinois - Davenport, Iowa	1901-1950	50
Peoria, Illinois	1905-1950	46
St. Louis, Missouri	1904-1950	47
Springfield, Illinois	1901-1950	50
Terre Haute, Indiana	1912-1950	39

Cooperative substation prior to 1942.

Although questionable in some instances, substation records of hail are probably more reliable than other forms of "days with" data recorded by volunteer observers. Because hail is an unusual event and occurs somewhat infrequently in Illinois, it probably attracts more attention from the



a. STATIONS WITH ACCEPTABLE HAIL DATA IN THE 1901-1950 PERIOD



b. PHYSIOGRAPHIC AND TOPOGRAPHIC MAP OF ILLINOIS

FIGURE 1 REFERENCE MAPS

observers than other weather phenomena that they are asked to report, such as thunderstorms, fog, haze, and high winds.

The problem presented by the questionable substation data was approached in two ways. The first method of evaluating and translating the data into annual and seasonal statistics was accomplished by plotting on individual maps all substation and First-Order station hail data for each year from 1901 through 1950. Then, lines of equal hail occurrences were drawn on each map to obtain an annual pattern. Next, a map overlay having grids representing square miles was constructed for Illinois. This overlay was then placed over each annual map, and an average numerical value was determined for each square from the underlying hail pattern. This technique was applied separately by two individuals to determine if significant variations might be created in the subjective analysis of the maps. However, this method met with failure because prolonged periods of poor records at several substations in certain areas, especially in southern Illinois, provided averages that were incompatible with those shown for nearby First-Order stations. This method was then discarded.

The second method for solving the problem of questionable substation hail records was much the same as that used in a previous report on thunderstorms.[2] Annual hail values for each substation were listed from 1901 through 1950. Then, the years of observer changes were marked along this listing. Obvious periods of time with very few or no hail reports could easily be observed and these periods of record discarded. These periods of unsatisfactory records were identified also with certain observers. Data reported during the entire period of service by these observers were not used in the hail analysis. Once these periods of questionable hail data had been eliminated, averages based on the remaining data were compared with those from nearby First-Order stations to determine if they were compatible. During the 50 years under study the number of cooperative substations in Illinois with hail records increased from 85 in 1901 to 238 in 1950.

Detailed examination and evaluation of substation records resulted in 85 stations, including 12 First-Order stations, with at least five years of satisfactory hail records. Due to inaccuracies in observations, most of the substations had considerably less than 50 years of acceptable hail records. Of the 85 stations used in the study, 50 stations, including 11 First-Order stations, had 20 or more years of acceptable records. The number of stations with acceptable records for various periods of years is shown in Table 2. The station locations are shown in Figure 1a, which also shows the approximate number of acceptable years for each station. The number of available stations with acceptable years of record varied only slightly from year to year. For instance, 43 stations had acceptable records in 1905 while there were 44 stations with acceptable records in 1950. Obviously, the number of stations with acceptable records did not increase proportionately with the increasing number of cooperative stations from 1901 through 1950.

TABLE 2

NUMBER OF STATIONS WITH ACCEPTABLE YEARS OF HAIL RECORDS FOR VARIOUS PERIODS DURING 1901 THROUGH 1950

Period of Record	Total Number of Stations	Number of First-Order Stations
5 or more years	85	12
10 or more years	77	11
15 or more years	60	11
20 or more years	50	11
25 or more years	41	11
30 or more years	31	11
40 or more years	17	9
50 years	9	5

ANNUAL HAIL

A study was made of the spatial distribution of hail in Illinois on an annual basis. In this phase of the study, efforts were concentrated on: calculation of averages and frequency distributions, evaluation of sampling errors, and investigation of physical factors affecting the hail distribution.

AREAL DISTRIBUTION

The average distribution of hail days is illustrated in Figure 2. County boundaries and the locations of ten major cities are shown in the background for reference purposes. In this figure, the average has been expressed in terms of number of days with hail in an average ten-year period, since the average number of days per year is relatively small. Figure 2 shows that the annual hail maximum occurs in the southwestern portion of central Illinois in the Springfield Plain. Secondary maxima are indicated in the extreme northwest portion, of the state in the Rock River Hill Country and Wisconsin Driftless Section and in the extreme southern part of the state in the Shawnee Hills and Mt. Vernon Hill Country. These regions are identified with physiographic divisions in Illinois(3) shown on Figure 1b. Areas of minimum occurrence are indicated in eastern Illinois and in north central Illinois and west of the Illinois River valley in the Galesburg Plain.

PHYSICAL FACTORS AFFECTING DISTRIBUTION

Hail statistics compiled by the U. S. Weather Bureau[4] and others show that the frequency of hail increases with elevation within areas of well-defined topographic differences. Although the hill regions of northwestern and southern Illinois do lot have elevations exceeding 1200 feet above mean

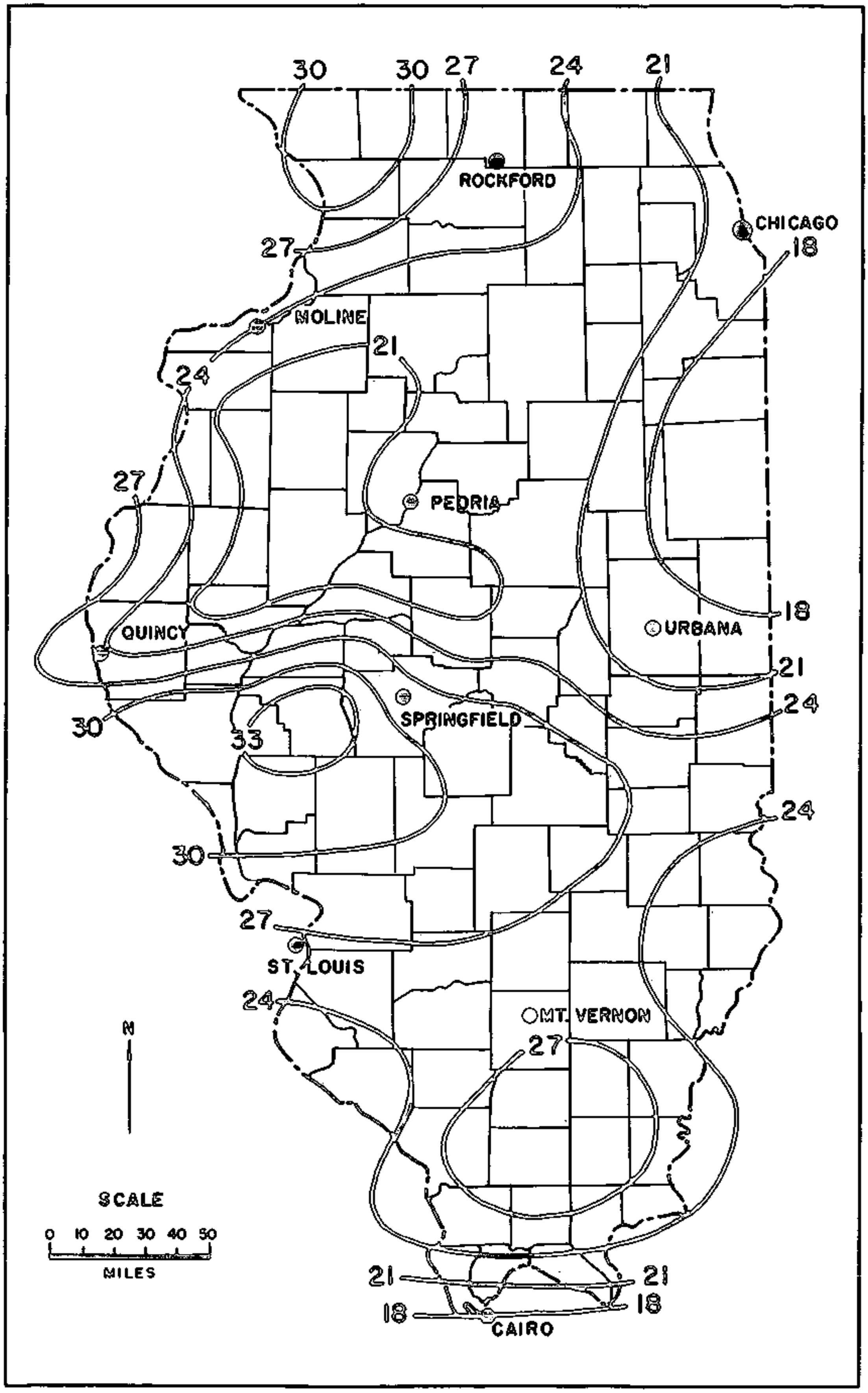


FIGURE 2 ANNUAL AVERAGE HAIL DISTRIBUTION EXPRESSED AS NUMBER OF DAYS WITH HAIL PER 10-YEAR PERIOD

sea level, they are comparatively rugged with uplands that are complexly dissected and hills that rise rather abruptly from the flat lands to the south, as shown in Figure 1b. Because the prevailing windflow is southerly, these flat lands lie upwind from the two hill areas. Consequently, it appears likely that the hail maxima in the extreme northwest and southern portions of the state are related to the abrupt changes in the local relief rather than to the relatively small differences in elevation within the regions. This subject will be treated in greater detail in a later section on relation of hail to elevation.

The area of maximum hail frequency in the state lies in the western portions of the Springfield Plain, which has no pronounced changes in relief in relation to the topography of the land surrounding it (Fig. 1b). According to the U. S. Weather Bureau,[4] this region lies within a hail belt of heavy activity extending from Oklahoma and Kansas east-northeastward across Missouri, Illinois, Indiana, and Ohio to Pennsylvania. The Weather Bureau has pointed out that this is a non-orographic maximum which coincides roughly with a region of strong frontal activity.

Figure 3 shows the annual frequency of thunderstorm days with rainfall of 0.10 inch or more.(2) The ten dots shown on this map and on subsequent figures in this report are cities which serve as location reference points and are named on Figure 2. Figure 3 was used for comparison of the hail and thunderstorm patterns. These two atmospheric phenomena are closely related. The 0.10-inch level was chosen for defining thunderstorm occurrences to minimize observational inconsistencies,[2] which may occur with very small amounts of rain; also, hail is generally associated with strong thunderstorm activity that produces rainfall in excess of 0.10 inch. Comparison of Figures 2 and 3 reveals a ridging in the thunderstorm pattern in the general region of the hail maxima in the southwestern part of central Illinois and in the northwestern region of the state. However, a similar ridge in thunderstorm frequency within the Shawnee Hills region is not indicated on Figure 3. Only a one-way increase to the south is evident across this area. A trough in the thunderstorm pattern is indicated west of the Illinois River valley near the hail minimum in that area shown in Figure 2. Also, there is some indication of a thunderstorm trough in eastern Illinois corresponding to the minimum in the hail pattern in this region.

Figure 4 shows the ratio of annual hail frequency to annual thunderstorm days with rainfall of 0.10 inch or more. The ratios are expressed in percent. Reference to this figure reveals relatively high ratios in northwestern Illinois, southern Illinois, and the southwestern portion of central Illinois associated with the hail maxima in these regions. Relatively low ratios are indicated in north central and northeastern Illinois. Another study(2) has shown that in eastern and northeastern Illinois 20 percent of the days with hail have no reports of thunderstorms, whereas in most of western and southern Illinois over 90 percent of the days with hail have thunderstorms.

RELIABILITY OF DISTRIBUTION PATTERN

Next, the reliability of the hail distribution pattern was investigated, since there was some question as to whether the hail maxima in northwestern, southwest central, and southern Illinois were persistent or had been induced by a few years of unusually frequent hail occurrences in these areas. As a test of the persistency of the average pattern, hail maps were drawn for each of five decades from 1901 through 1950. These are shown in Figure 5. Reference to these maps shows that the three areas of maximum activity tend to persist in the same general pattern throughout the five decades, although some deviations from the average pattern (Fig. 2) are apparent in separate decades.

The map for 1901 through 1910 shows areas of high hail frequency in the northwestern part of the state and in the Springfield Plain in the approximate positions of the maxima shown by Figure 2. The Shawnee Hills - Mt. Vernon Hill Country maximum is not pronounced, but low frequency areas in eastern Illinois and in the Galesburg Plain are shown.

Figure 5b for the second ten-year period, 1911 through 1920, shows the northwestern and Springfield Plain maxima, and an indication of the Shawnee Hills - Mt. Vernon Hill Country maximum in southern Illinois. A low frequency area is again shown in the eastern part of the state and the Galesburg Plain.

Figure 5c for 1921 through 1930 shows regions of high frequency in northwestern Illinois and in the southwestern portion of central Illinois, although the regions are not in the exact positions shown by the average pattern of Figure 2. Again, the Shawnee Hills-Mt. Vernon Hill Country maximum is shown and low frequency areas in eastern Illinois and west of the Illinois River are indicated, in general agreement with the average pattern.

The fourth ten-year period, 1931 through 1940, does not agree as well with the average pattern of Figure 2 as do the three previous decades. However, in some regions, especially in the high frequency area of the Springfield Plain, there is excellent correspondence between the average and decade patterns. The northwestern Illinois maximum is indicated, but it extends farther southeastward in the 1931 through 1940 period than indicated by the average pattern (Fig. 2) or by any of the maps for the three previous ten-year periods. A region of frequent activity is indicated in the Shawnee Hills, but apparently is an extension of a high, centered to the south over the Coastal Plain rather than in the hill region. Low frequency areas again are indicated in northeastern Illinois and west of the Illinois River.

The last ten-year period, 1941 through 1950, shown in Figure 5e, has areas of high occurrence in the Shawnee Hills and the Rock River Hill Country of northwestern Illinois. A third high area is shown in the southwestern part of central Illinois but it extends northeastward across the state to Peoria rather than eastward as shown by the average pattern of Figure 2. The low fre-

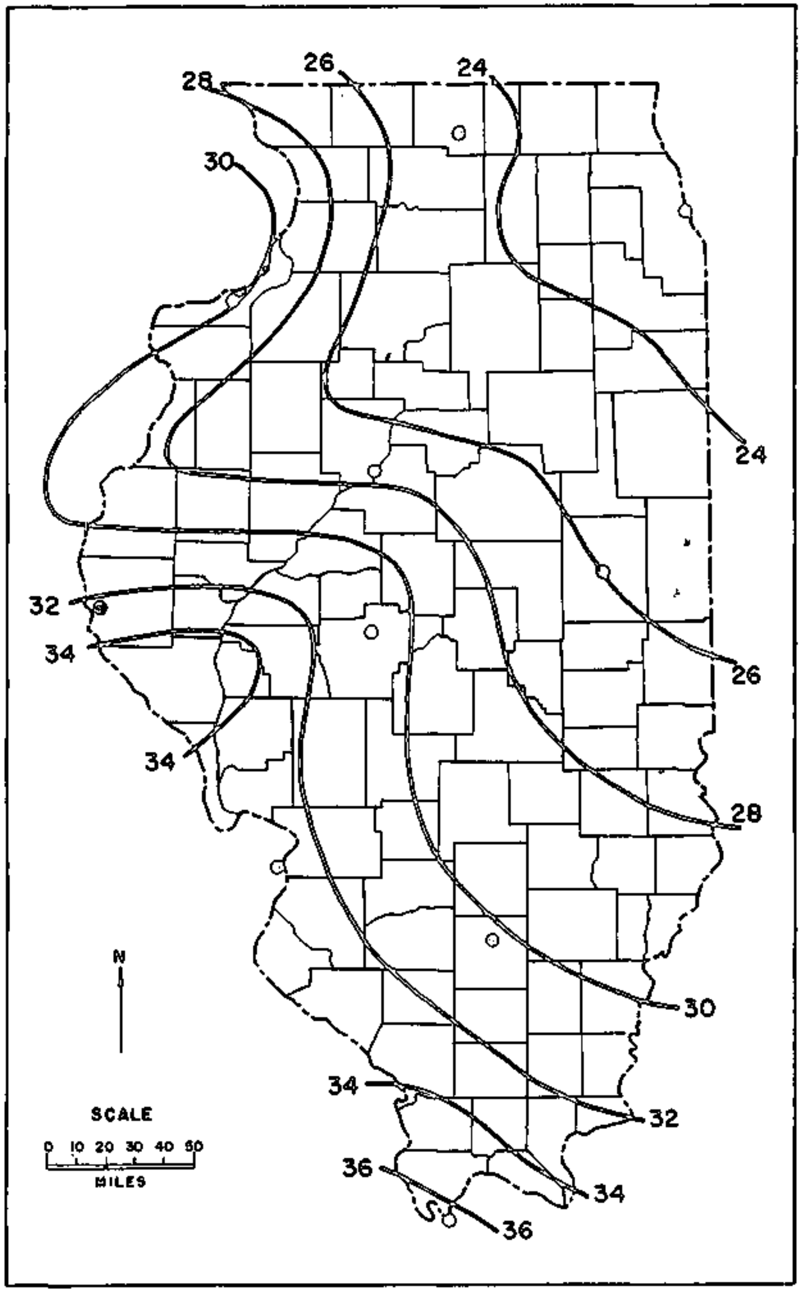


FIGURE 3 FREQUENCY OF THUNDERSTORM DAYS PER YEAR WITH RAINFALL OF 0.10 INCH OR MORE

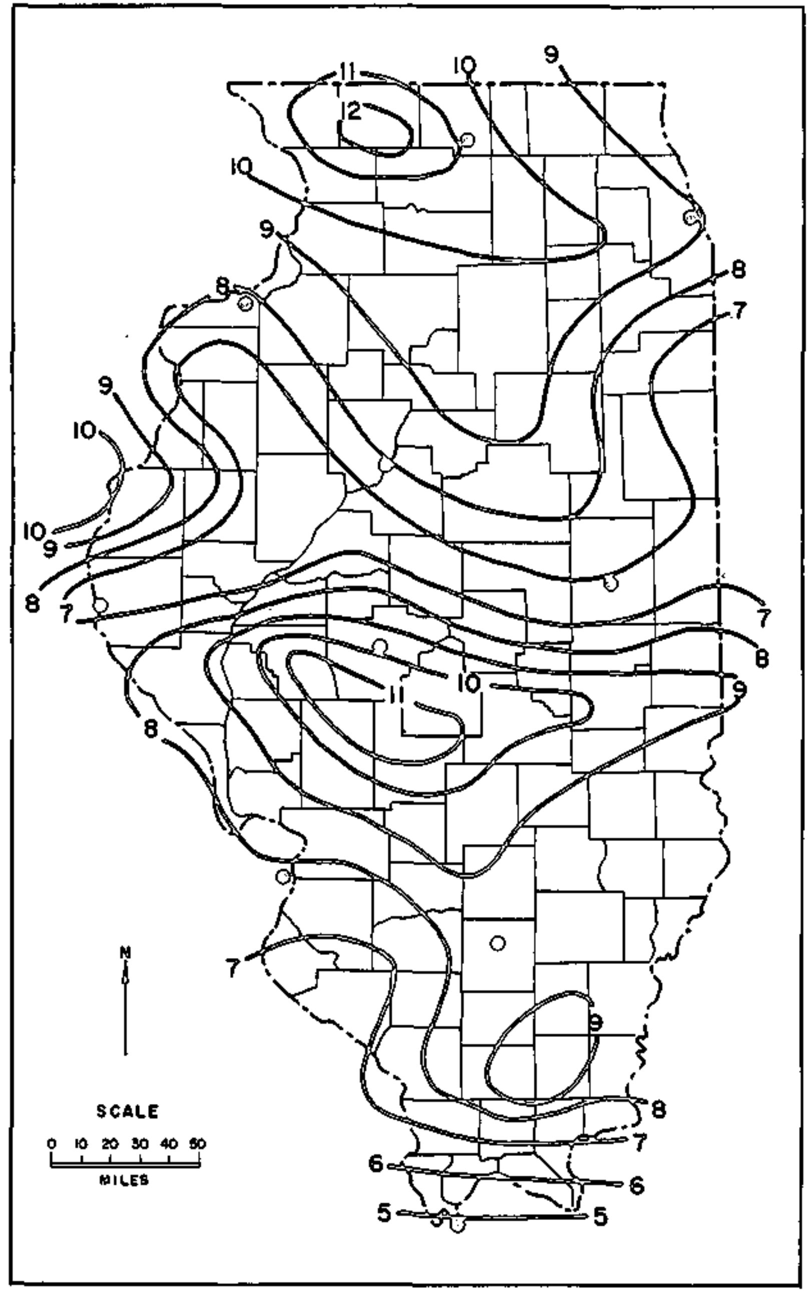


FIGURE 4 RATIO OF ANNUAL HAIL DAYS TO THUNDERSTORM DAYS WITH RAINFALL OF 0.10 INCH OR MORE

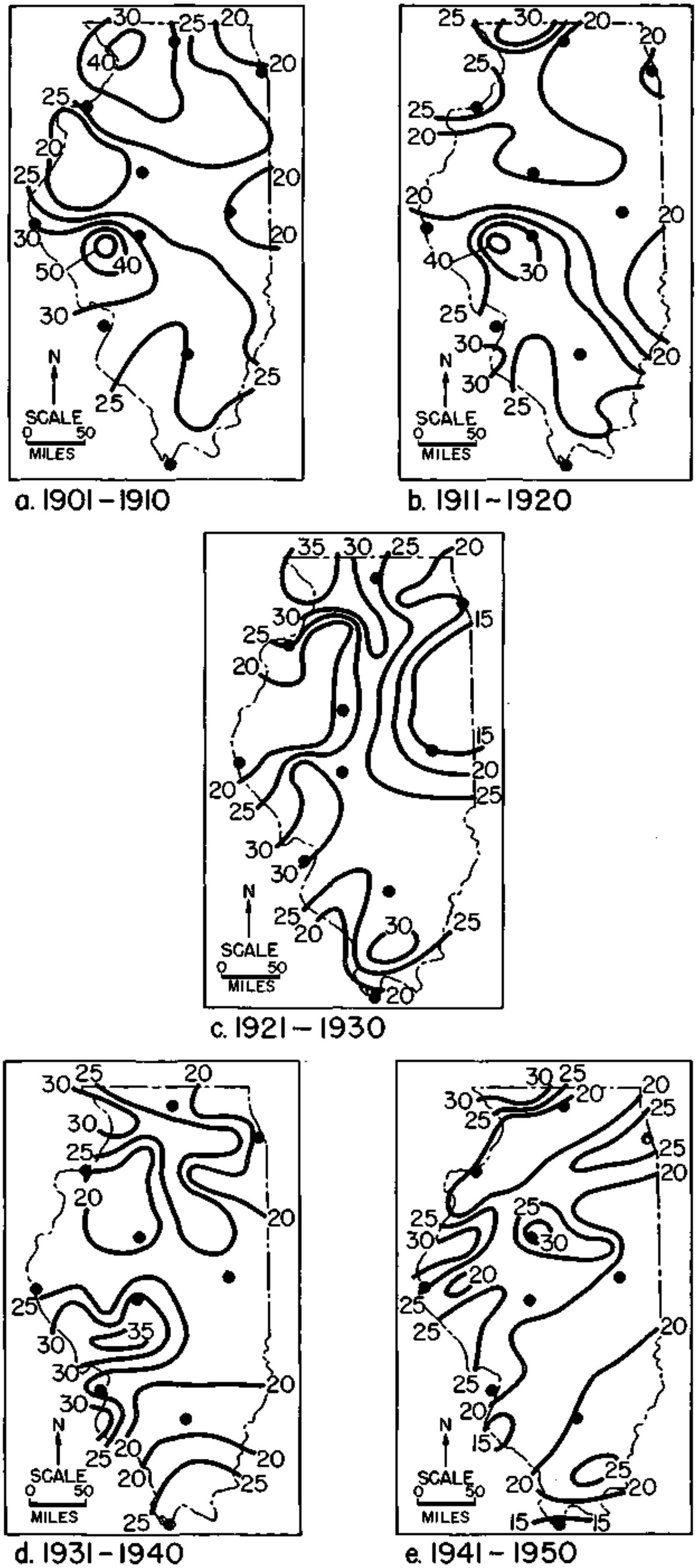


FIGURE 5 NUMBER OF HAIL DAYS PER DECADE

quency area in the western portions of the Galesburg Plain is not very pronounced. In most cases, the five ten-year periods show patterns basically similar to the average pattern of Figure 2 with respect to approximate location of outstanding features.

SAMPLING ERRORS ASSOCIATED WITH POINT AVERAGES

Although the ten-year patterns in Figure 5 show considerable similarity to the average pattern of Figure 2, differences in shape of pattern, exact location of areas of high and low frequency, and magnitude of the ten-year averages are sufficient in some instances to indicate that ten-year periods are unsatisfactory for defining the average distribution of hail in the state. To further investigate the sampling requirements for defining the average number of hail days per year, a study was made of the temporal variability of hail at U. S. Weather Bureau First-Order stations by use of moving averages. Stations used in this phase of the analysis were Springfield, St. Louis, Cairo, Peoria, Chicago, and Moline. Moving averages were calculated for periods of 40, 30, 25, 20, 15, and 10 years. Average and maximum deviations from the average or mean number of hail days per year, based on the long-term 1901 through 1950 records, were then determined for each period of the moving averages at each station. The deviations were expressed in percent, and the results are summarized in Table 3. Thus, at Springfield by averaging all ten of the 40-year moving averages it was found that the average deviation from the 1901 through 1950 mean was two percent, while the maximum deviation among the ten individual 40-year moving averages was seven percent. For 25-year periods, the average deviation was found to be three percent and the maximum was ten percent, while for 10-year periods the average was eight percent and the maximum was 28 percent. As one would expect, the deviations or sampling errors increased with decreasing observational period.

Table 3 shows that relatively large errors can be introduced in the average frequency of hail when a ten-year period is used to compute the average at a station. As this table indicates, an observational period of 25 years or longer should be used to keep the sampling error at a level of 20 percent or less. If a ten-year period is used, errors up to approximately 50 percent may be introduced in the average frequency at a single point.

To obtain a measure of the year-to-year variability in the annual number of hail days, the coefficient of variation of annual hail at various stations in the state was calculated. The results of these calculations indicated that a coefficient of variation of approximately 73 percent was representative for stations throughout the state. The coefficient of variation formula is:

$$CV(\%) = SD \times \frac{100}{m}$$

where CV = coefficient of variation, SD = standard deviation, and m = the period average. The relatively great time variability of hail is indicated by the magnitude of the coefficient.

TABLE 3

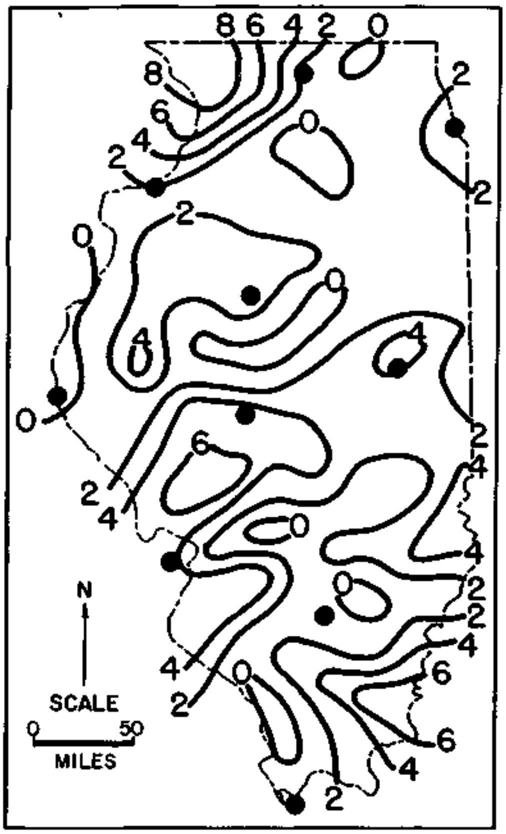
RELIABILITY OF ANNUAL HAIL AVERAGES BASED ON VARIOUS SAMPLING PERIODS

Deviation (%) from 1901 through 1950 Mean for Averages Based on Given Base Periods (yrs.)

Deviation	40	30	25	20	15	10
Springfield						
Average	2	5	3	5	6	8
Maximum	7	7	10	7	14	28
St. Louis						
Average	4	4	9	11	14	16
Maximum	7	11	15	22	22	30
Cairo						
Average	4	4	6	7	11	13
Maximum	6	11	16	16	21	32
Peoria						
Average	-	2	5	8	6	13
Maximum	-	5	9	14	14	36
Chicago						
Average	3	7	8	9	17	19
Maximum	5	10	15	20	25	50
Moline						
Average	9	16	18	16	19	25
Maximum	13	22	22	30	43	52
All Stations Combined						
Average	5	6	8	9	12	16
Maximum	13	22	22	30	43	52

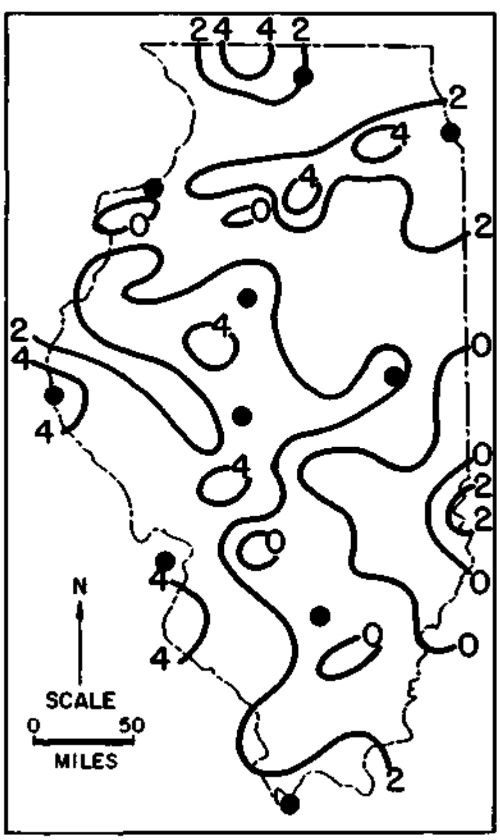
To illustrate further the year-to-year variability in the number and distribution of hail days in the state, maps for four separate years have been presented in Figure 6. On these maps, the hail distributions for 1911, 1912, 1935, and 1936 are shown. Figure 6a shows that a relatively large number of hail days were recorded over a large portion of the state during 1911. Hail was most frequent in the northwest, central, and southeast portions of the state. The number of hail days at individual stations ranged from zero to nine.

The map for 1912 indicates that some areas received a large number of hailstorms, although a smaller area of the state experienced these extreme values than in 1911. The concentration of hail was principally in west central and south central Illinois where as many as nine hail days were recorded at individual stations.

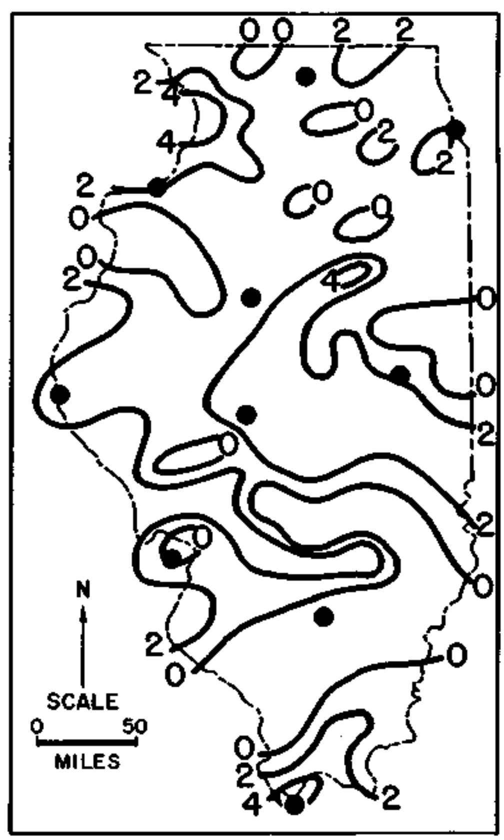


a. HAIL 1911

b. HAIL 1912



c. HAIL 1935



d. HAIL 1936

FIGURE 6 NUMBER OF HAIL DAYS IN SELECTED YEARS

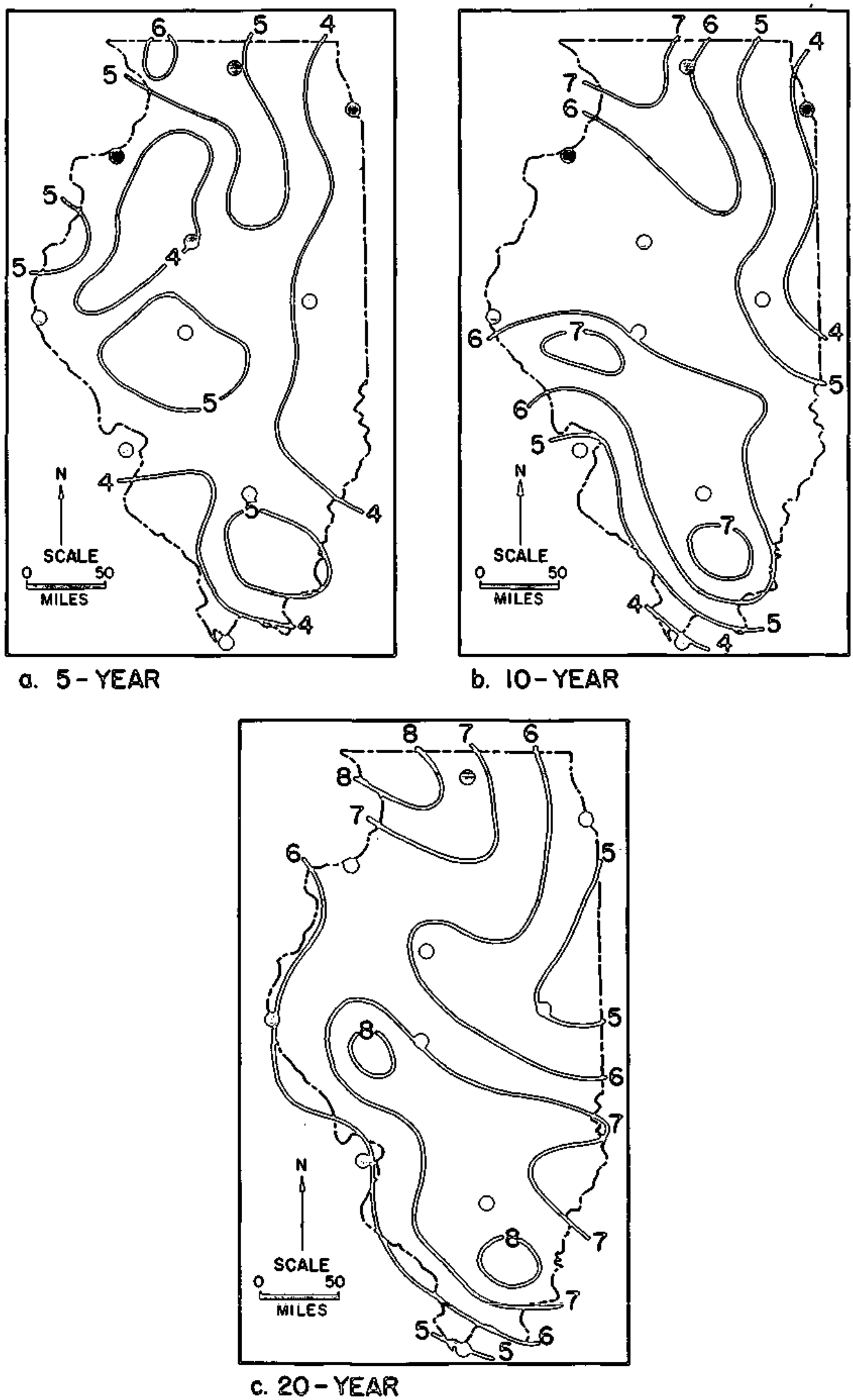


FIGURE 7 FREQUENCY DISTRIBUTION OF ANNUAL HAIL DAYS

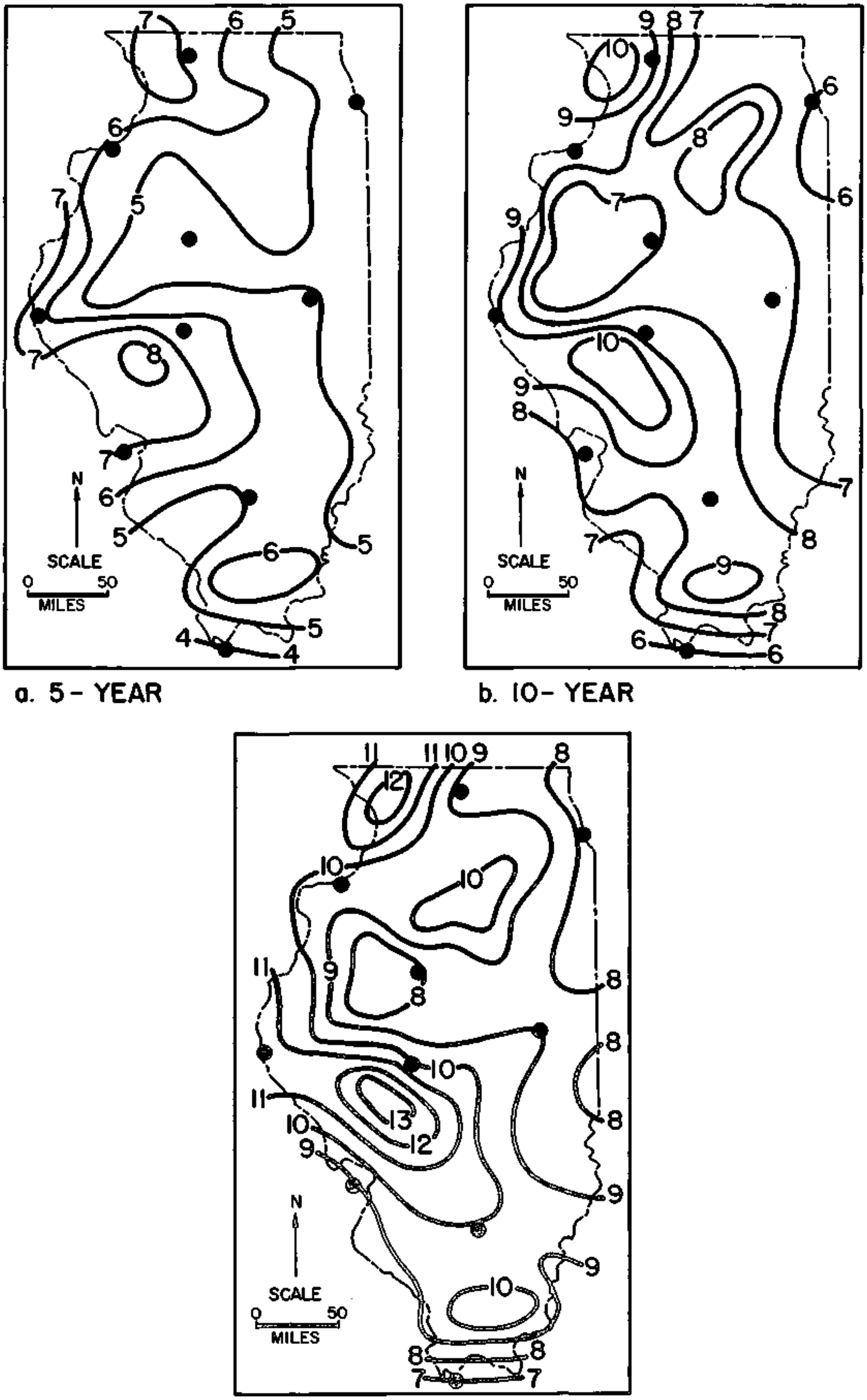


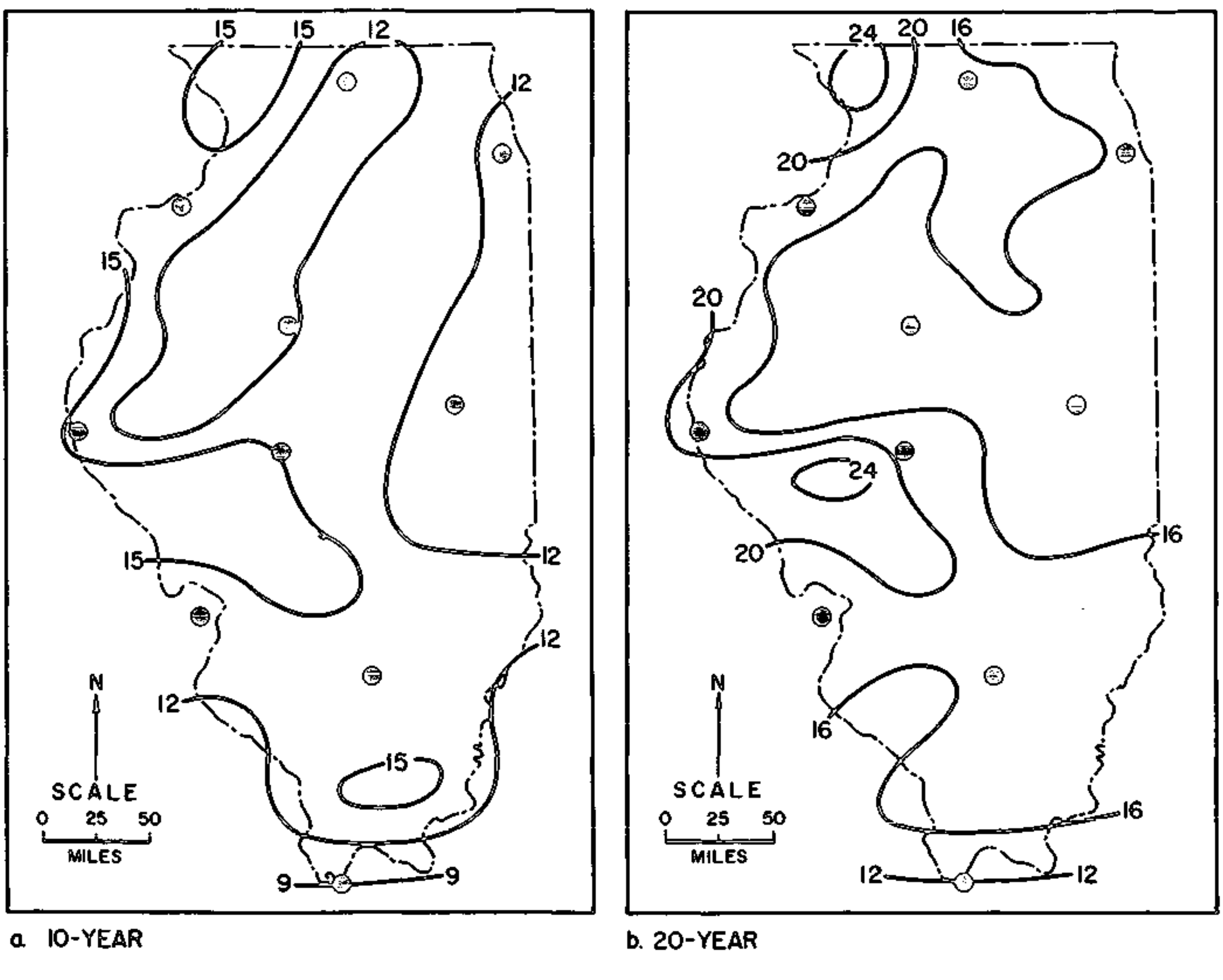
FIGURE 8 FREQUENCY DISTRIBUTION OF 2-YEAR HAIL DAYS

Figure 6c shows the distribution in 1935, a year when hail was relatively sparse in the state. The maximum number of days with hail recorded at any station was four and the majority of the stations had none or one. The year 1936 (Fig. 6d) was again one of relatively few hail days. The maximum number was four, while zero or one was recorded over most of the state.

As indicated earlier, Figure 2 shows the average hail distribution for the state. In order to obtain a measure of the reliability of the pattern that it shows, calculations of the standard deviation and coefficient of variation of the averages for individual stations were made. Results of these calculations indicate that the coefficient of variation of the average at any point is approximately 15 percent. That is, if a similar period of records was analyzed, there are two chances out of three that the average values indicated in Figure 2 would be within 15 percent of those indicated by the new sample. There is only one chance in twenty that a new sample average would differ by more than 30 percent from the average values of this figure at any given point. Although the coefficients of variation of the annual hail averages are not extremely large, these coefficients do show that great emphasis should not be placed on apparently small changes in shape and magnitude of the areal hail pattern in Illinois shown in Figure 2.

FREQUENCY DISTRIBUTION

To provide additional information on the distribution of hail in the state, the frequency distribution for individual stations was calculated. Results of these calculations are summarized in Figure 7. Figure 7a shows the number of hail days which will be equaled or exceeded on an average of one year in five at any given point. Thus, referring to Figure 7a, it is seen that in extreme northwestern Illinois an average five-year period will have one year in which there will be at least six hailstorms at each point in the region; or stating it more realistically, in 10 years out of a 50-year period, there will be six or more hailstorms per year at any given point in this area. Figures 7b and 7c show 10-year and 20-year frequency distributions, respectively. As would be expected, Figure 7 indicates patterns similar to Figure 2 with maximum occurrences in northwestern, southwest central, and extreme southern Illinois and a minimum in the eastern part of the state. The low occurrence



a. 10-YEAR b. 20-YEAR

FIGURE 9 FREQUENCY DISTRIBUTION OF 5-YEAR HAIL DAYS

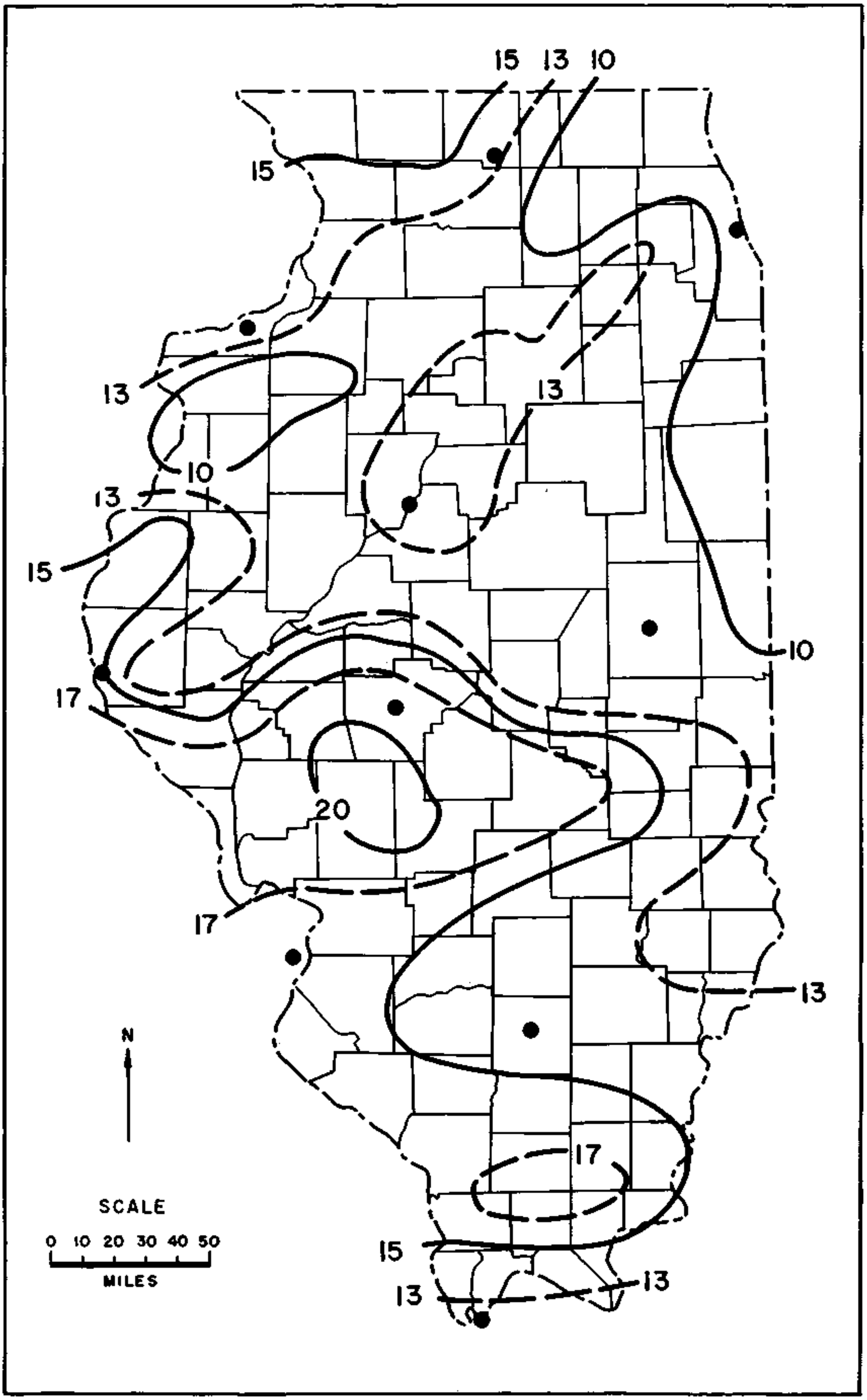


FIGURE 10 SPRING AVERAGE HAIL DISTRIBUTION EXPRESSED AS NUMBER OF DAYS WITH HAIL PER 10-YEAR PERIOD

area west of the Illinois River valley is pronounced on the 5-year frequency map but becomes less distinguishable on the 10- and 20-year maps.

To obtain a measure of the probability of abnormal hail occurrences over several consecutive years an additional frequency analysis was made. In this analysis, the frequency distribution of the maximum number of hail days in two consecutive years and in five consecutive years was calculated for various stations throughout the state. Results of these computations are summarized in Figures 8 and 9.

The map in Figure 8a indicates the maximum number of hail days within two consecutive years which will occur once in an average five-year period or ten times in 50 years. For example, at points in extreme northwestern Illinois there will be ten times in 50 years when the total number of hail days for two consecutive years will equal or exceed seven. Similarly, Figures 8b and 8c indicate that five times in 50 years there will be a two-year total of ten or more hail days at points in extreme northwestern Illinois, while once in an average 20-year period there will be a two-year total of 12 or more in this area. Again, the distribution patterns shown in Figure 8 are similar in shape, orientation, and location to those shown for average annual hail in Figure 2; that is, peaks in the patterns occur in northwestern, southwest central, and extreme southern Illinois, while areas of relatively infrequent hail occurrences are present in eastern Illinois and in the region west of the Illinois River valley.

Figure 9 is similar to Figure 8, except that recurrence intervals are shown for hail totals over periods of five consecutive years. Thus, Figure 9a shows the maximum number of hail days during five consecutive years which may be expected to occur once during an average 10-year period or five times during a 50-year period. Patterns again are similar to the average pattern of Figure 2.

SEASONAL HAIL

Analysis was made of the distribution of hail days during various seasons, with primary emphasis on spring and summer. Most of the hail is experienced and the probability of crop damage is greatest in these two seasons.

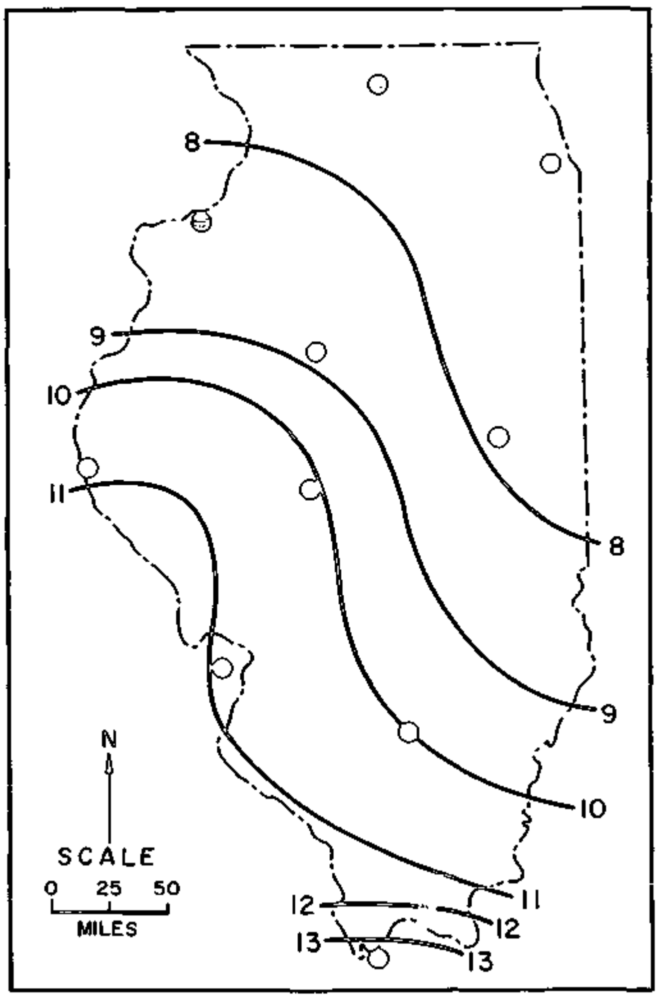


FIGURE 11 FREQUENCY OF SPRING THUNDERSTORM DAYS WITH RAINFALL OF 0.10 INCH OR MORE

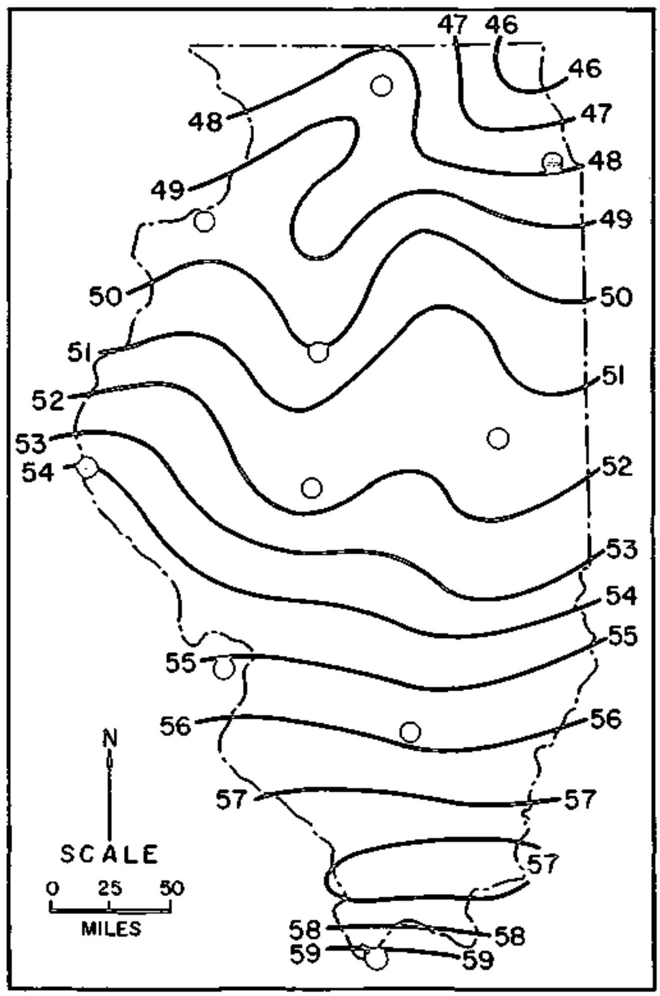


FIGURE 12 SPRING MEAN TEMPERATURES

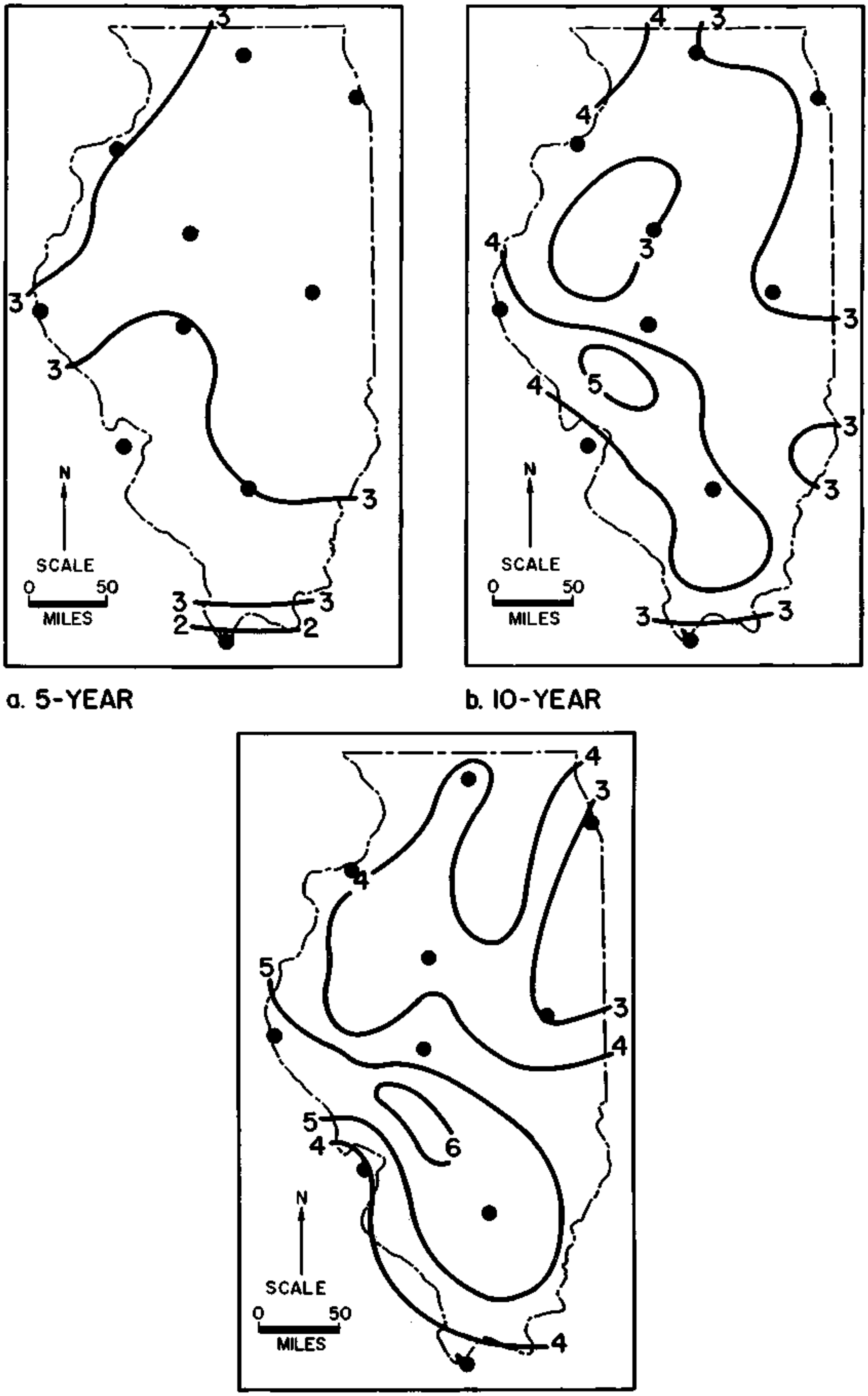


FIGURE 13 FREQUENCY DISTRIBUTION OF HAIL DAYS IN SPRING

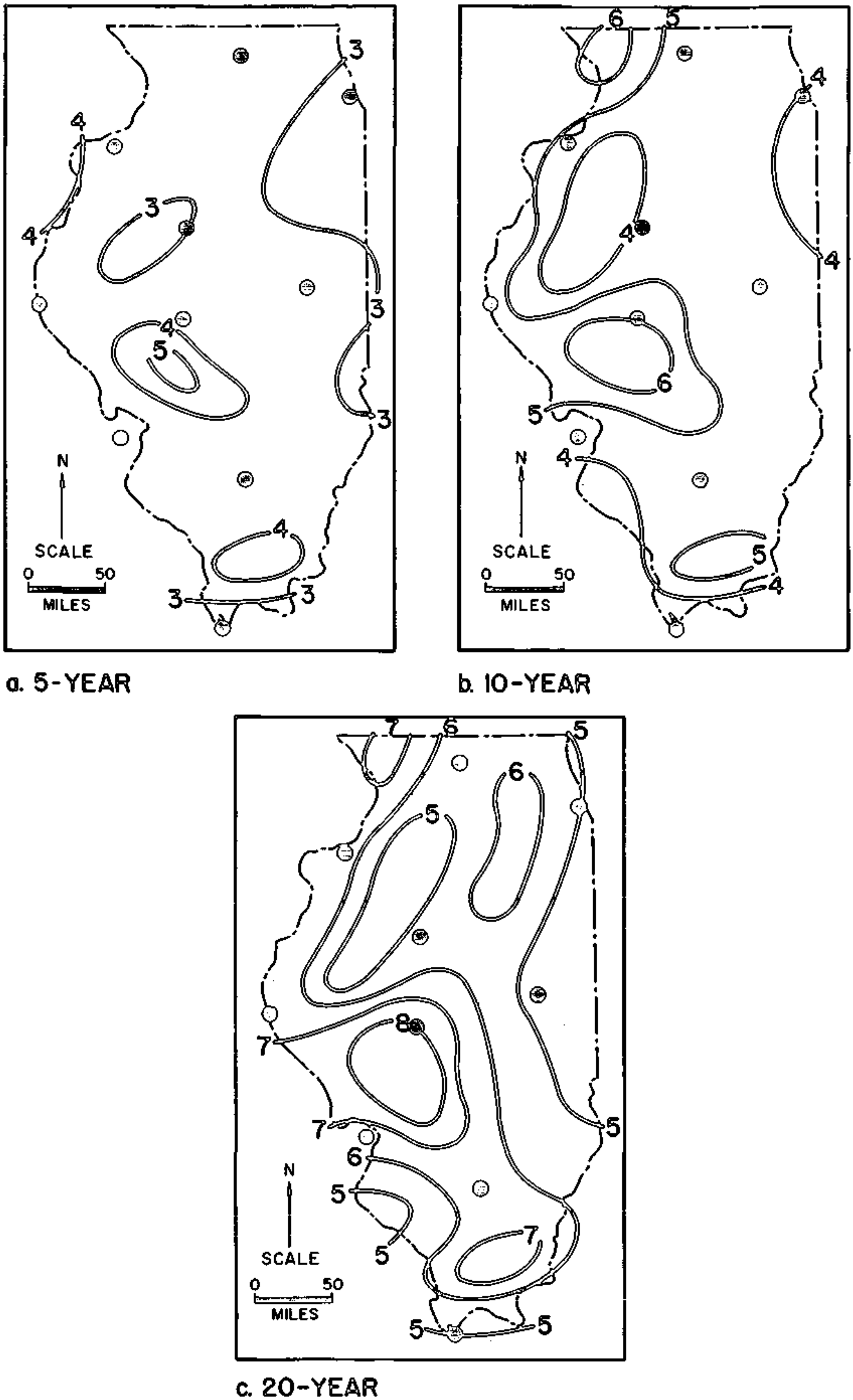


FIGURE 14 FREQUENCY DISTRIBUTION OF 2-YEAR HAIL DAYS IN SPRING

SPRING DISTRIBUTION

Figure 10 shows the average hail distribution during March through May, defined here as spring. The averages are expressed in number of spring hail days in an average ten-year period. Comparison of Figure 10 with the average annual map of Figure 2 reveals considerable similarity between the patterns. In both cases, the maximum is in the Springfield Plain, although the spring maximum is slightly southeast of the annual maximum. There is an area of relatively high frequency in the Shawnee Hills region. Both the spring and annual maps show a high area in northwestern Illinois, although the high is more pronounced on the annual map. Both maps show a low area in the eastern portion of the state. The low, west of the Illinois River valley on the annual map, is not pronounced in spring.

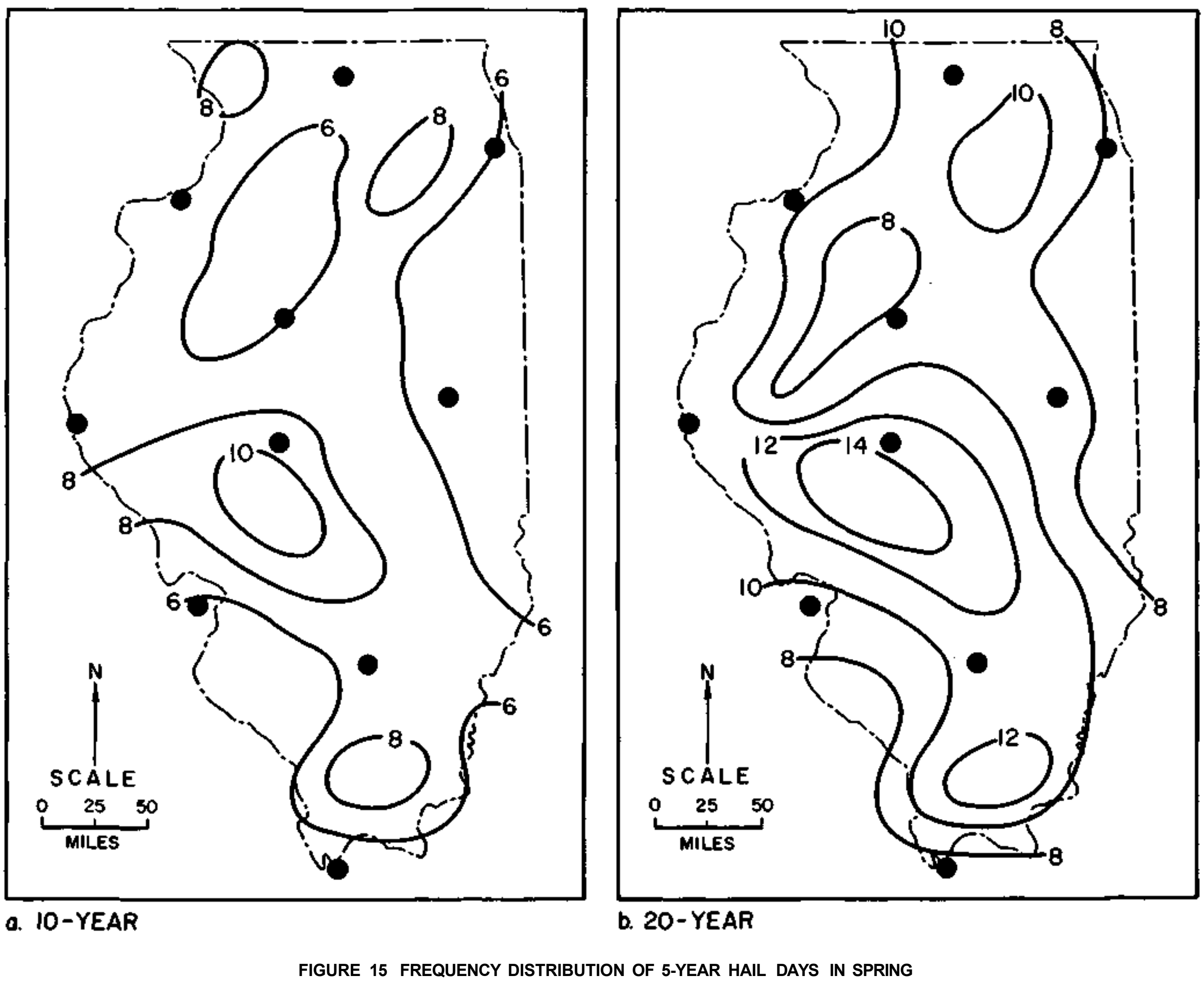
To obtain a measure of the reliability of the hail distribution map of Figure 10, the coefficient of variation of the spring averages was calculated. Results indicate a coefficient of variation of 16 percent for spring, compared to 15 percent for the annual averages.

Figure 11 shows the frequency of thunderstorm days during spring with a rainfall of 0.10 inch or more.[2] Figures 10 and 11 do not show as many striking similarities as existed between annual hail and thunderstorm days (Figs. 2-3). However, the spring thunderstorm frequency map (Fig. 11) does show a ridging effect in the general region of the hail maximum in the Springfield Plain and some indications of a ridging effect in the northwestern part of the state.

Figure 12 shows the mean temperature distribution for spring. It is interesting to note that a relatively cool area exists in the Shawnee Hills region, synonomous with the hail maximum in that area. Also, a ridge in the temperature field in western Illinois corresponds quite closely with the area of maximum thunderstorm frequency in that region.

Spring is the season of most frequent hailstorms in Illinois. Using all stations with 20 years or more of acceptable records, it was found that on the average 53 percent of the annual number of hail days occurs during spring in the northern half of the state and approximately 61 percent in the southern part of the state.

Figure 13 shows the number of spring hail days which will be equaled or exceeded during



a. 10-YEAR

b. 20-YEAR

FIGURE 15 FREQUENCY DISTRIBUTION OF 5-YEAR HAIL DAYS IN SPRING

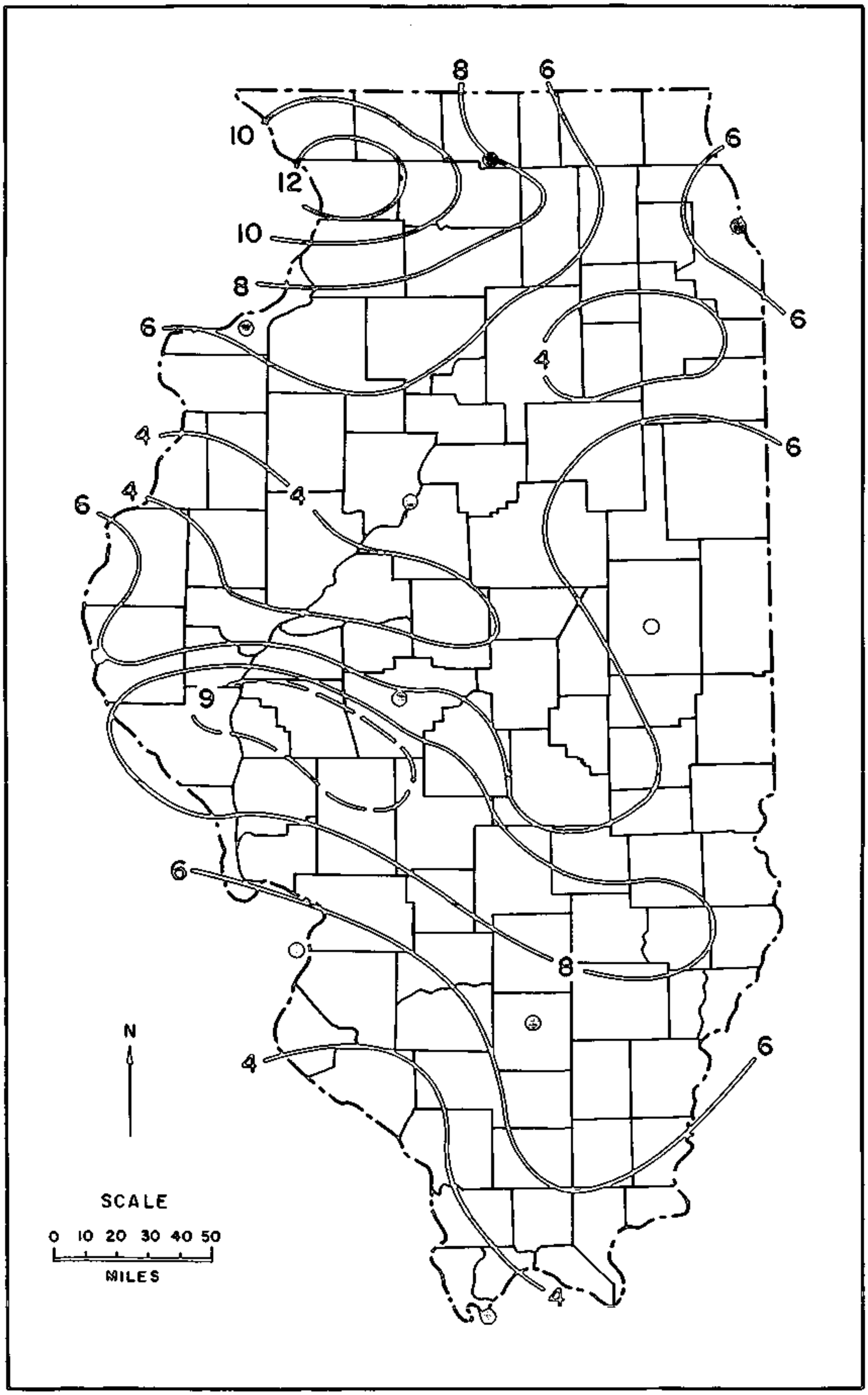


FIGURE 16 SUMMER AVERAGE HAIL DISTRIBUTION EXPRESSED AS NUMBER OF DAYS WITH HAIL PER 10-YEAR PERIOD

one spring within average periods of 5, 10, and 20 years. Interpretation of these maps is the same as described for the frequency distributions depicted by the annual maps of Figure 7. Figure 13a shows a rather uniform distribution over the state of the once in five-year occurrences, which range from three to four hail days in southern and western Illinois to two to three days over the remainder of the state. Greater range in the distribution is shown by the 10-year and 20-year maps in Figures 13b-c.

Figures 14 and 15 show the frequency distribution of consecutive two-year and five-year hail totals for spring. Thus Figure 14a shows the maximum number of hail days to be expected during two consecutive springs once within an average five-year period or ten times during a fifty-year period. Interpretation of Figures 14 and 15 is the same as discussed previously for annual hail days (Figs. 8-9).

SUMMER DISTRIBUTION

The average distribution of hail days during the three summer months of June, July, and August is shown in Figure .16. Reference to this map shows hail maxima in northwestern Illinois and the southwest part of central Illinois. These maxima are located similarly to those on the map for annual averages (Fig. 2). Also, pronounced

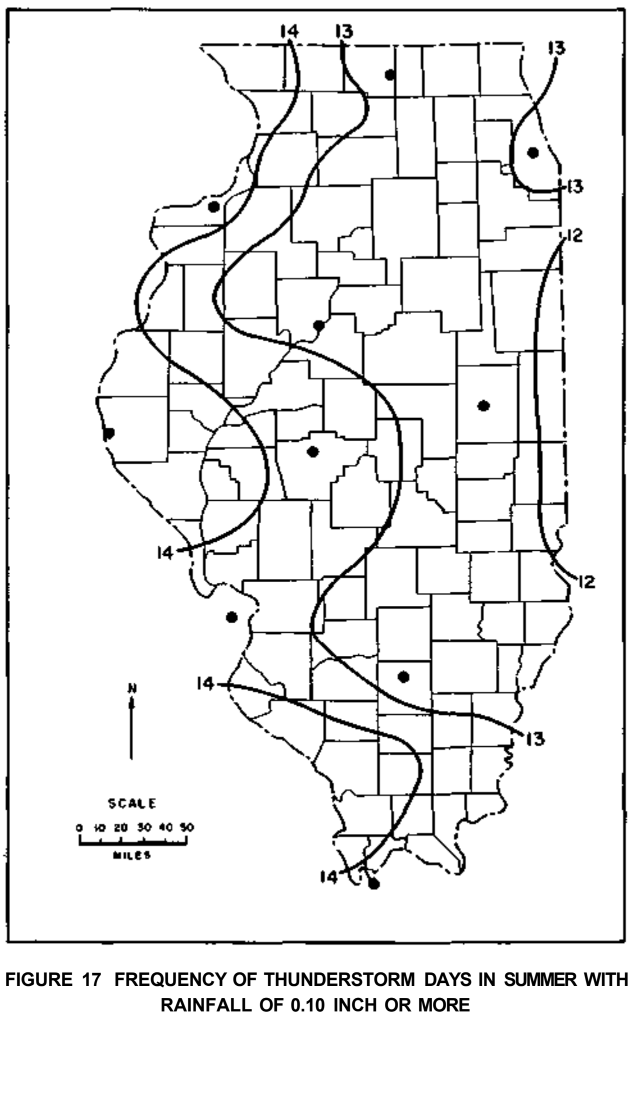


FIGURE 17 FREQUENCY OF THUNDERSTORM DAYS IN SUMMER WITH RAINFALL OF 0.10 INCH OR MORE

hail minima are found in the Galesburg Plain and the Illinois River valley in summer. However, the Shawnee Hills maximum and the eastern Illinois minimum of Figure 2 are not present on the summer map. Furthermore, in summer the area with the highest frequency of hail days is in northwestern Illinois rather than the southwest part of central Illinois. Also, Figure 16 shows a minor region of high hail frequency in the Chicago area, which appears as a region of relatively low frequency on the annual and spring maps. Comparison of the spring and summer maps reveals that the number of hail days decreases throughout the state in summer.

The coefficient of variation of the averages for summer (Fig. 16) was found to be 23 percent, compared to 16 percent and 15 percent for spring and annual averages, respectively. Thus, the reliability of the summer frequency distribution is less than that for the annual and spring distributions shown in Figures 2 and 10.

The frequency of thunderstorm days in summer with rainfall of 0.10 inch or more is shown in Figure 17.(2) In northwestern and southwest central Illinois, high frequency areas are indicated on both maps, but close agreement elsewhere is not indicated.

The average percent of the annual hail occurring in summer exceeds 40 percent in the Rock River Hill Country of northwestern Illinois, while a large area in southern Illinois has less than 20 percent of its annual hail in summer. The state average is 26 percent for summer as compared to 57 percent in spring.

Figure 18 shows the number of hail days in summer which will be equaled or exceeded once during average periods of 5, 10, and 20 years. Figures 19 and 20 show the frequency distribution of the maximum number of hail days in summer for two consecutive and five consecutive years. The interpretation of Figures 18 to 20 is the same as that described for annual hail (Figs. 7-9).

During July and August, corn and soybeans, the major crops of the state, are normally in stages of growth most susceptible to hail damage. Consequently, an investigation was made of the hail distribution during these two months. The average hail frequency, expressed as the average number of July-August hail days per ten years, is given in Figure 21.

This figure shows similarities between the July-August distribution, the summer distribution, and the annual distribution. The greatest frequency of hailstorms during the July-August period is found in the extreme northwestern part of the state in the Rock River Hill-Wisconsin Driftless Section. Secondary maxima are indicated in the Springfield Plain region and in extreme eastern Illinois. Areas of relatively low frequency for these two months are indicated in the central and north central portions of the state.

Figure 22 shows the maximum number of hail occurrences recorded in any single year during

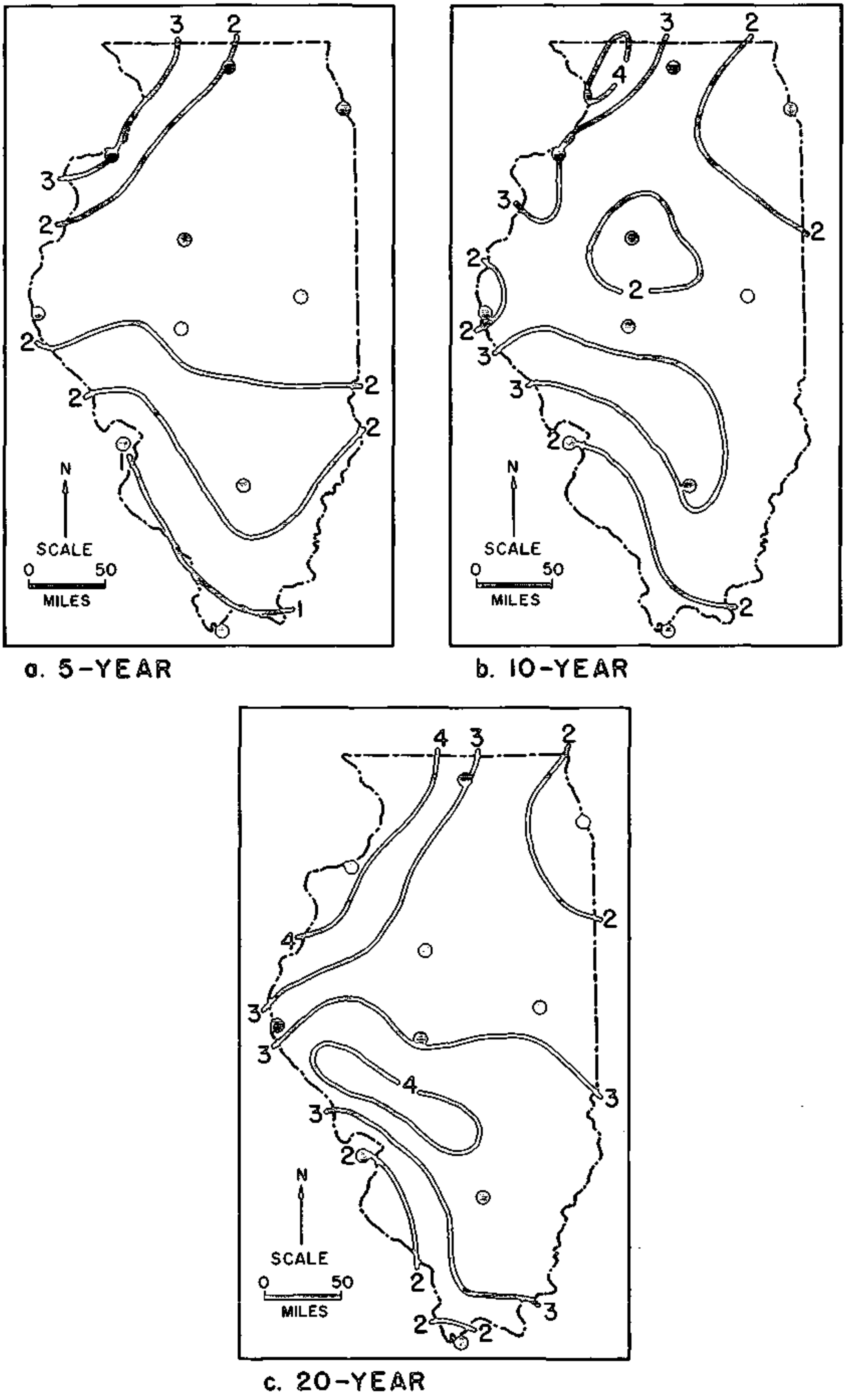


FIGURE 18 FREQUENCY DISTRIBUTION OF HAIL DAYS IN SUMMER

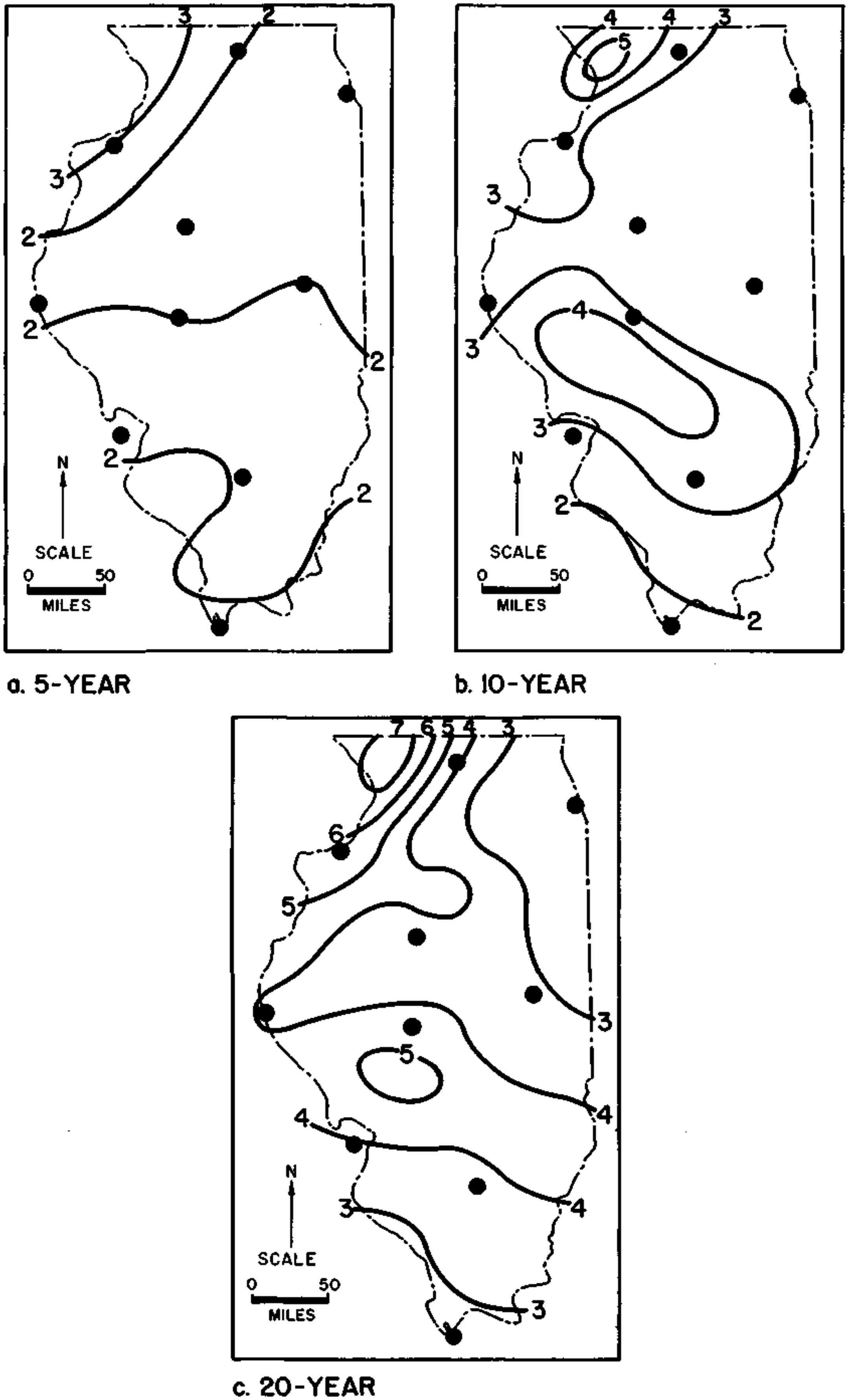
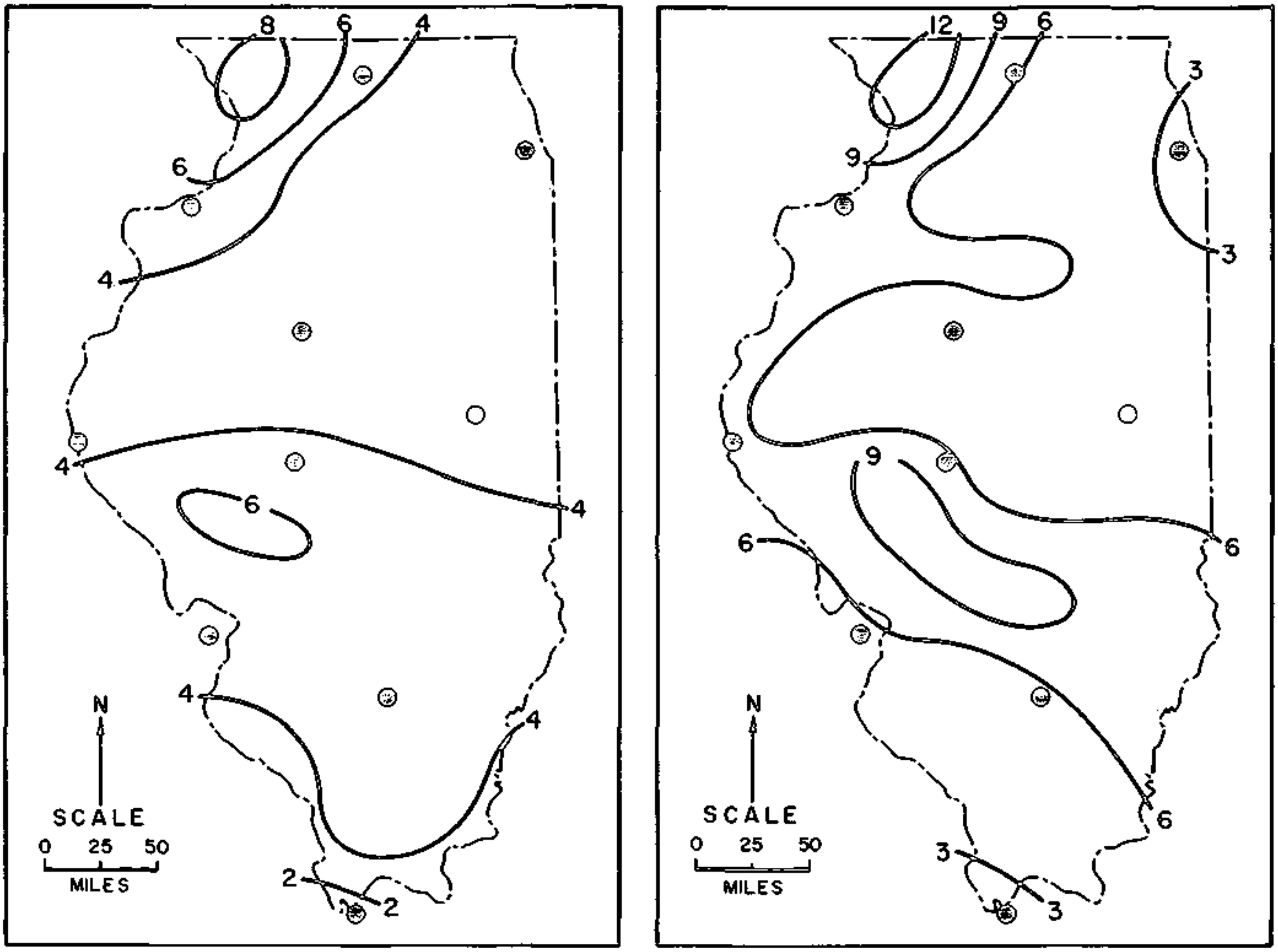


FIGURE 19 FREQUENCY DISTRIBUTION OF 2-YEAR HAIL DAYS IN SUMMER



a. 10-YEAR   b. 20-YEAR

FIGURE 2D FREQUENCY DISTRIBUTION OF 5-YEAR HAIL DAYS IN SUMMER

the July-August period, based upon stations with acceptable records for 20 years or longer. This map indicates that more than two hailstorms in any year during this two-month period is very unusual. Over 75 percent of the stations did not exceed two occurrences per year during their period of record. Only 11 percent of the stations recorded more than three hailstorms during this period in any one year.

SPRING-SUMMER DISTRIBUTION

An analysis of hail distribution was performed for the combined spring and summer seasons, which include the months of March through August. As mentioned previously, this is the period when most hail occurs in Illinois, and this period also includes the major portion of the growing season throughout the state. Approximately 83 percent of the annual hail occurrences in Illinois are recorded in this six-month period.

Figure 23 shows the March through August hail pattern. This map reveals marked similarities to the average annual distribution (Fig. 2).

Figure 24 shows the frequency of thunderstorms with rainfall of 0.10 inch or more during March through August/[2]) Excellent correlation between the hail and thunderstorm patterns is indicated. Ridges in the thunderstorm pattern appear over northwestern and southwest central Illinois in the same general regions as the hail maxima. As with the average annual distribution, the thunderstorm pattern does not indicate a ridge over the Shawnee Hills region corresponding with the hail maximum in that area. Low areas in the eastern part of the state and west of the Illinois River valley are shown on both the thunderstorm and hail frequency maps.

Figure 25 is a mean temperature map for the March through August period. It is interesting to note that there is a relatively cool area in the mean temperature pattern corresponding approximately with the hail maximum in the Shawnee Hills region. Similarly, there is a trough in the temperature pattern in extreme northwestern Illinois in the region of a hail maximum and to a lesser extent in the southern portion of west central Illinois where the primary hail maximum exists.

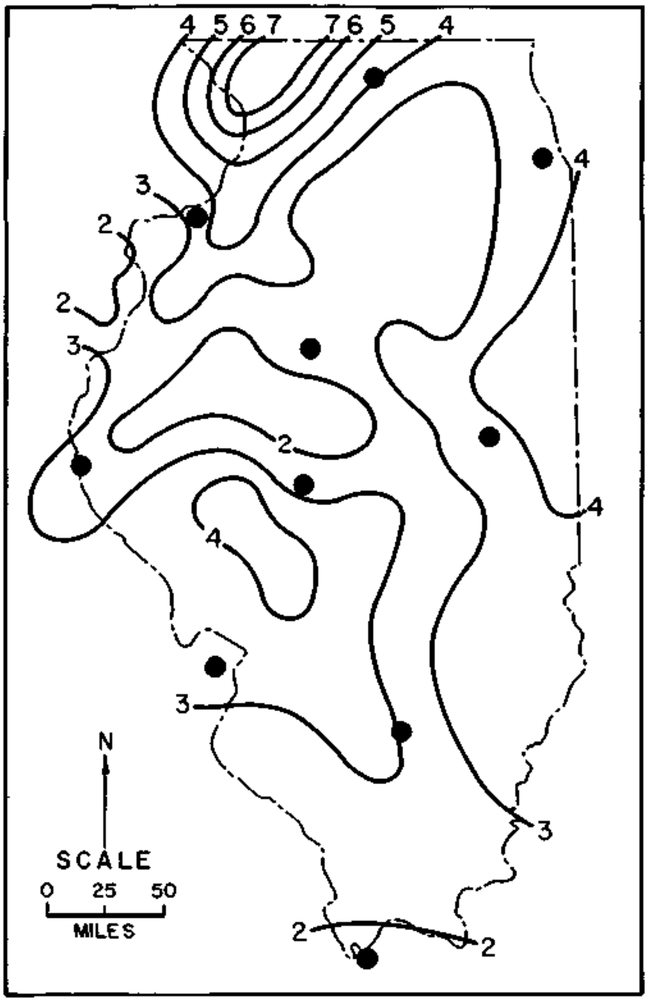


FIGURE 21 TOTAL NUMBER OF DAYS WITH HAIL IN JULY-AUGUST DURING AVERAGE 10-YEAR PERIOD

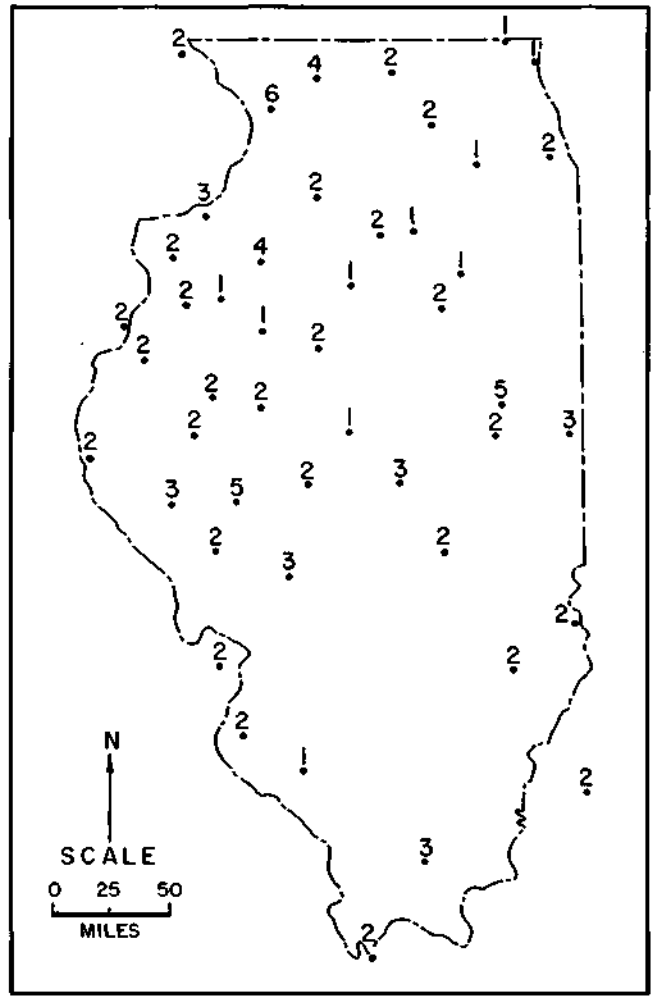


FIGURE 22 MAXIMUM NUMBER OF HAIL DAYS RECORDED IN ANY SINGLE YEAR DURING JULY-AUGUST

In general, the months of maximum number of hail days are March, April, or May in the southern portion of the state and April, May, or June in the northern half of the state, as shown in Figure 26. March is the month of maximum occurrence in southern Illinois and in small portions of •western and central Illinois. April is first or second in the number of hail days over three-fourths of the state, ranking first in northwestern, east central, and most of southeastern Illinois. May ranks first in much of the central part of the state and in portions of southeastern Illinois. In most of the state, June ranks fourth highest in hail frequency; only in northern Illinois does it assume higher ranking.

The four consecutive months of heaviest activity are March, April, May, and June, except for extreme northern and northeastern Illinois, where July replaces March in the four-month maximum, as indicated in Figure 27.

FALL AND WINTER DISTRIBUTIONS

Figure 28 shows the average number of days with hail in a ten-year period for the fall months, September through November. The Springfield Plain maximum is present but not pronounced. Another high in the extreme western part of the state is part of a ridge extending from that area northeastward to northern and northwestern Illinois. Minimum occurrences in fall are in the extreme eastern and south central portions of the state as well as along the Illinois River valley. In general, autumn hail is too infrequent to be an important factor in agricultural considerations. On the average, 11 percent of the annual hail days are recorded in fall.

Figure 29 shows the average frequency of hail days for winter, which includes the months of December through February. Hail is an infrequent phenomenon during winter, particularly in the northern half of the state. Less than one percent of the total annual occurrences is recorded in extreme northern Illinois, while almost ten percent occurs in southern Illinois. As a whole, the state averages six percent of its annual hail days in winter.

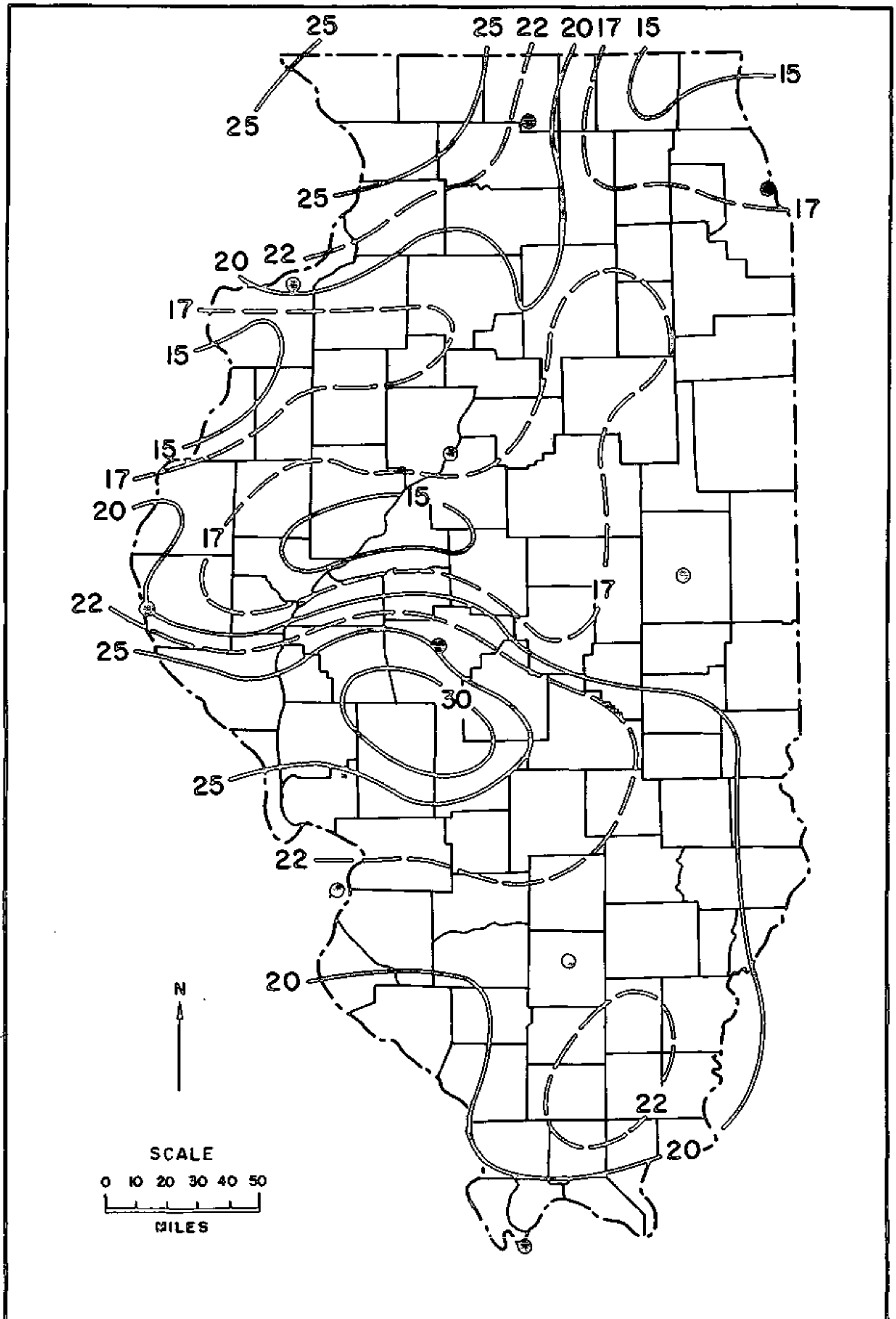


FIGURE 23 AVERAGE HAIL DISTRIBUTION DURING MARCH-AUGUST EXPRESSED AS NUMBER OF DAYS WITH HAIL PER 10-YEAR PERIOD

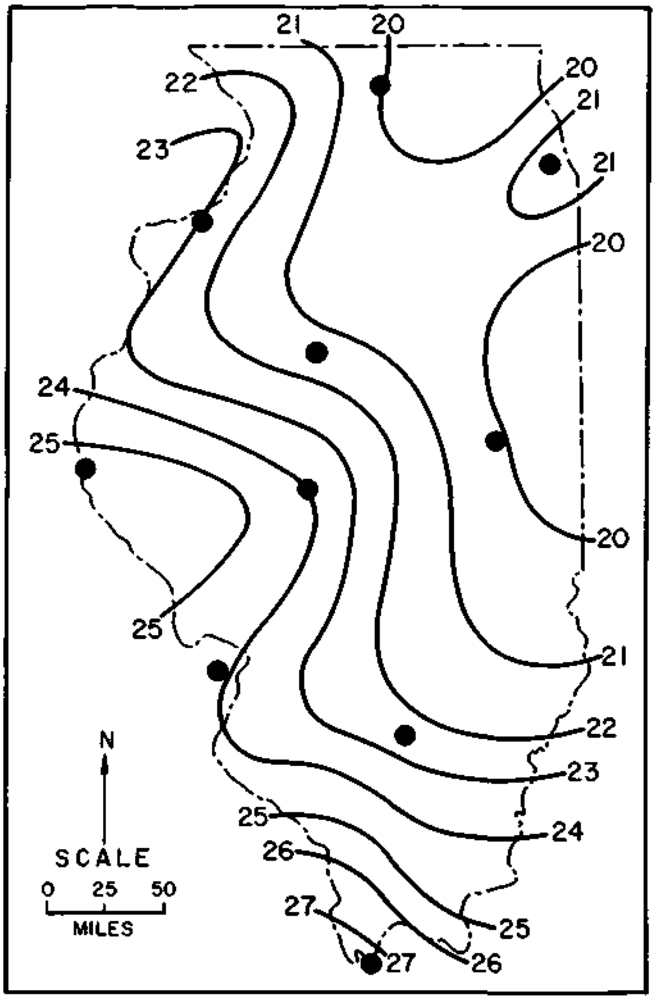


FIGURE 24 FREQUENCY OF THUNDERSTORM DAYS DURING MARCH-AUGUST WITH RAINFALL OF 0.10 INCH OR MORE

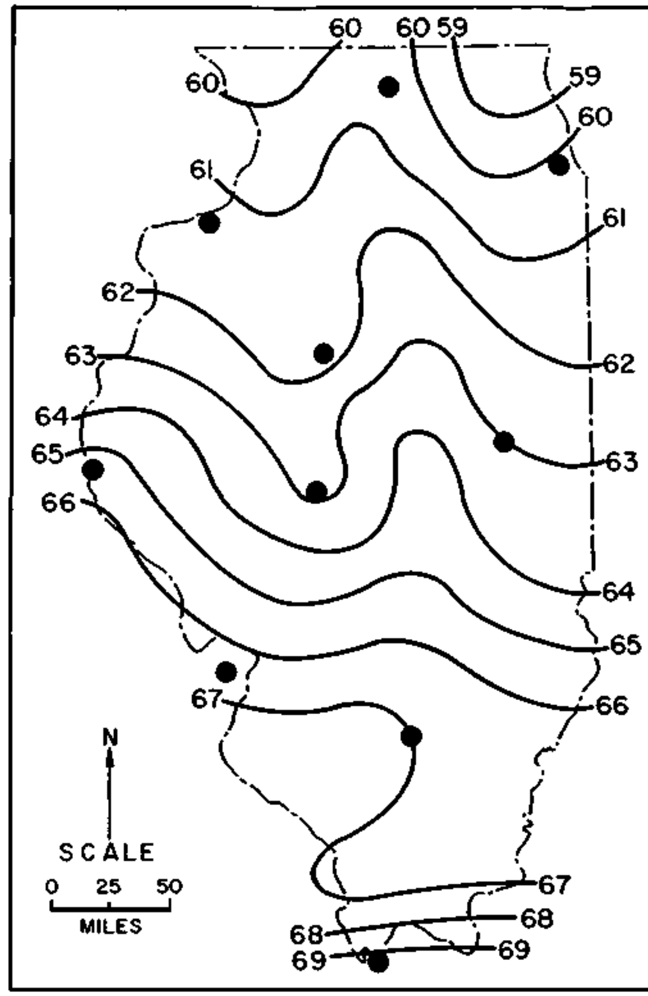


FIGURE 25 MARCH-AUGUST MEAN TEMPERATURES

ANNUAL AND SEASONAL HAIL EXTENT

A detailed study of the number of stations reporting hail days at least once during each year, during March through August, and during July-August was undertaken. Stations with acceptable records in the 1926 through 1950 period were used in the analysis. During these 25 years, the average number of stations with acceptable records was 42 per year with a range of from 49 in 1942 to 37 in 1933 and 1934. On the average, 88 percent of the stations recorded at least one hail day per year. However, in 1933 and 1935, 100 percent of the stations with acceptable records reported at least one hail day. The percent of stations recording one or more hail days went as low as 69 percent in 1949. The range in the annual percentage values for the 25 years was rather small. In 19 years, the values were within a range of +8 percent of the average.

The average percent of stations reporting at least one hail day in the March through August period was 82, only six percent lower than the average for the entire year. In 1933, 100 percent of the stations had at least one day of hail in this six-month period, while in 1949 only 64 percent reported hail days.

During the July-August period, when hail is most likely to cause the greatest crop damage in Illinois, only 25 percent of the stations, on the average, reported at least one day of hail. However, 53 percent of the stations reported at least one day of hail during this two-month period in 1931, and 51 percent of the stations reported hail days in 1938. The percentage of stations reporting hail days during the July-August period has considerably more year-to-year variability than the percentages for the March through August period and for the entire year. The lowest percentage of stations reporting at least one day of hail during July and August was five percent in 1935.

These statistics indicate that during an average year almost 90 percent of Illinois, or 50,000 square miles, has at least one day of hail some time during the year. In an average year, more than 80 percent of the state experiences at least one day of hail during the six months of maximum hail activity, March through August. Data for July and August indicate that in an average year approximately 25 percent of Illinois experiences one day or more of hail in these two months.

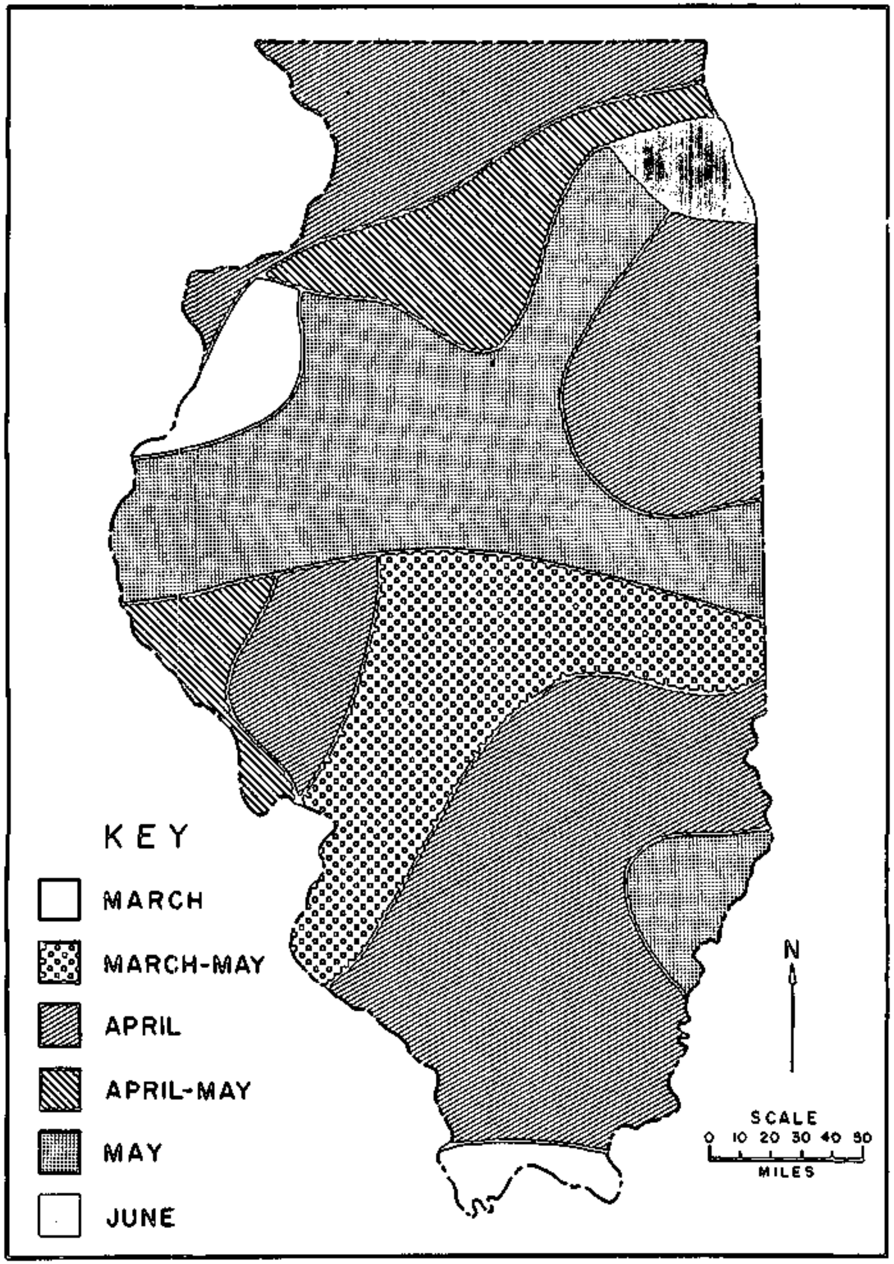


FIGURE 26 MONTHS OF MAXIMUM HAIL DAYS

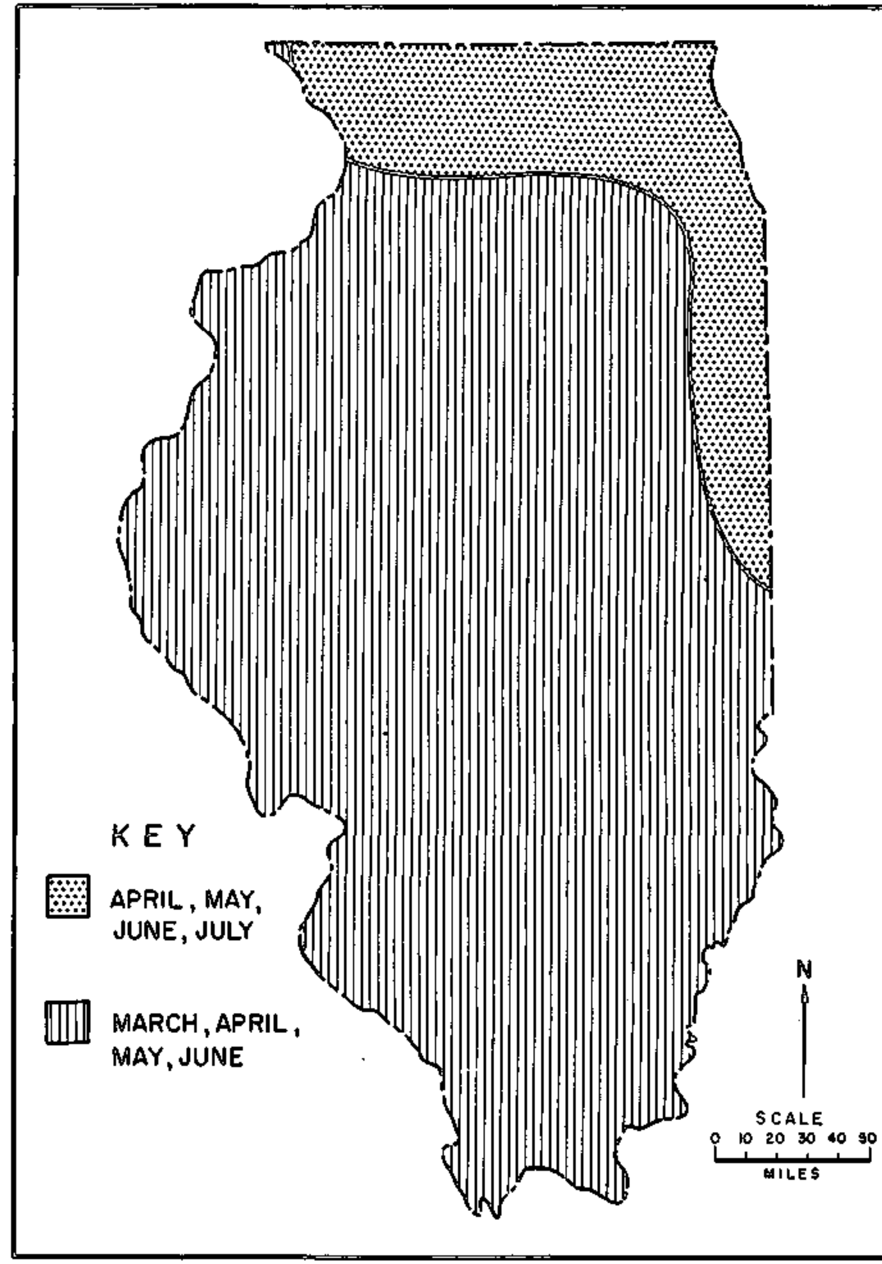


FIGURE 27 FOUR CONSECUTIVE MONTHS WITH MAXIMUM NUMBER OF HAIL DAYS

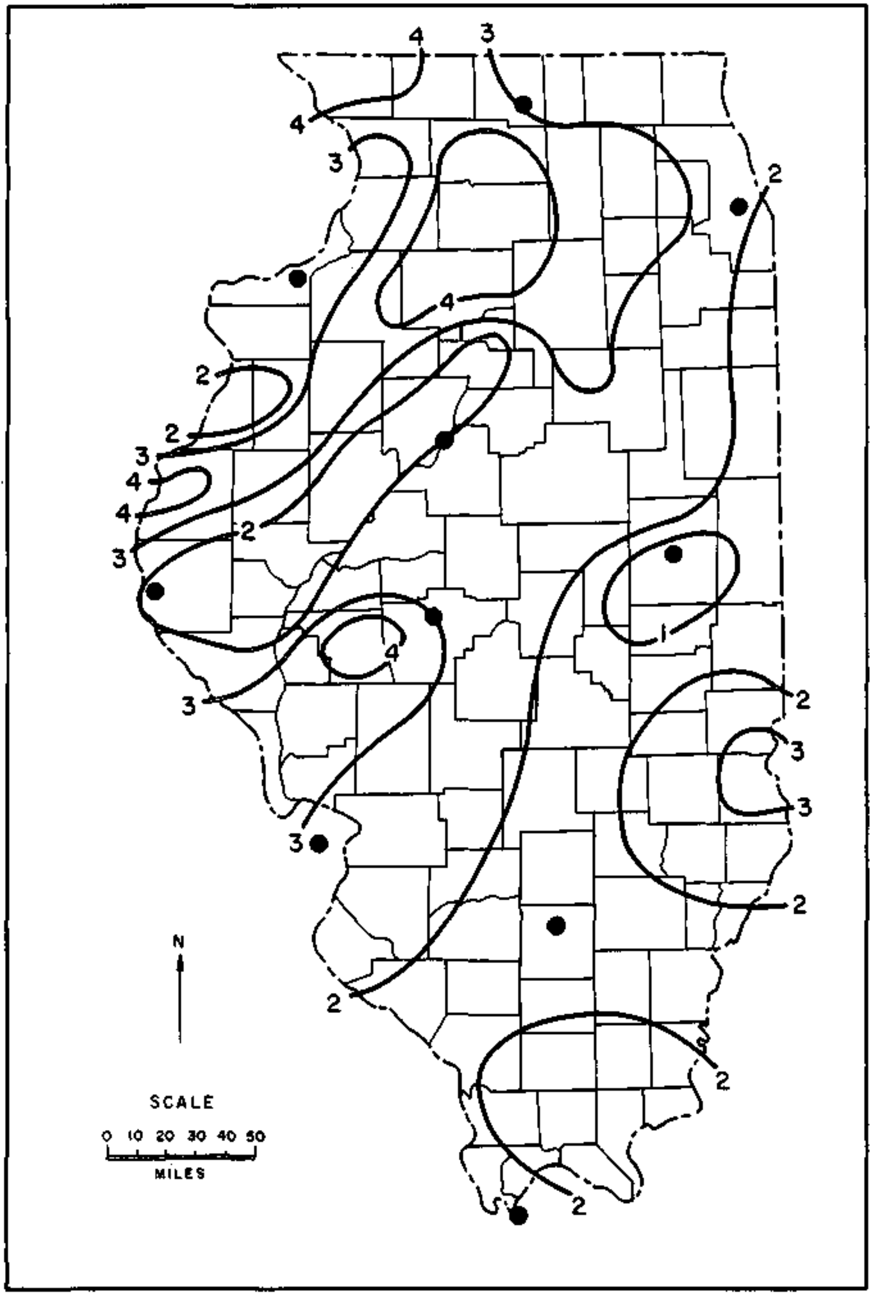


FIGURE 28 FALL AVERAGE HAIL DISTRIBUTION EXPRESSED AS NUMBER OF DAYS WITH HAIL PER 10-YEAR PERIOD

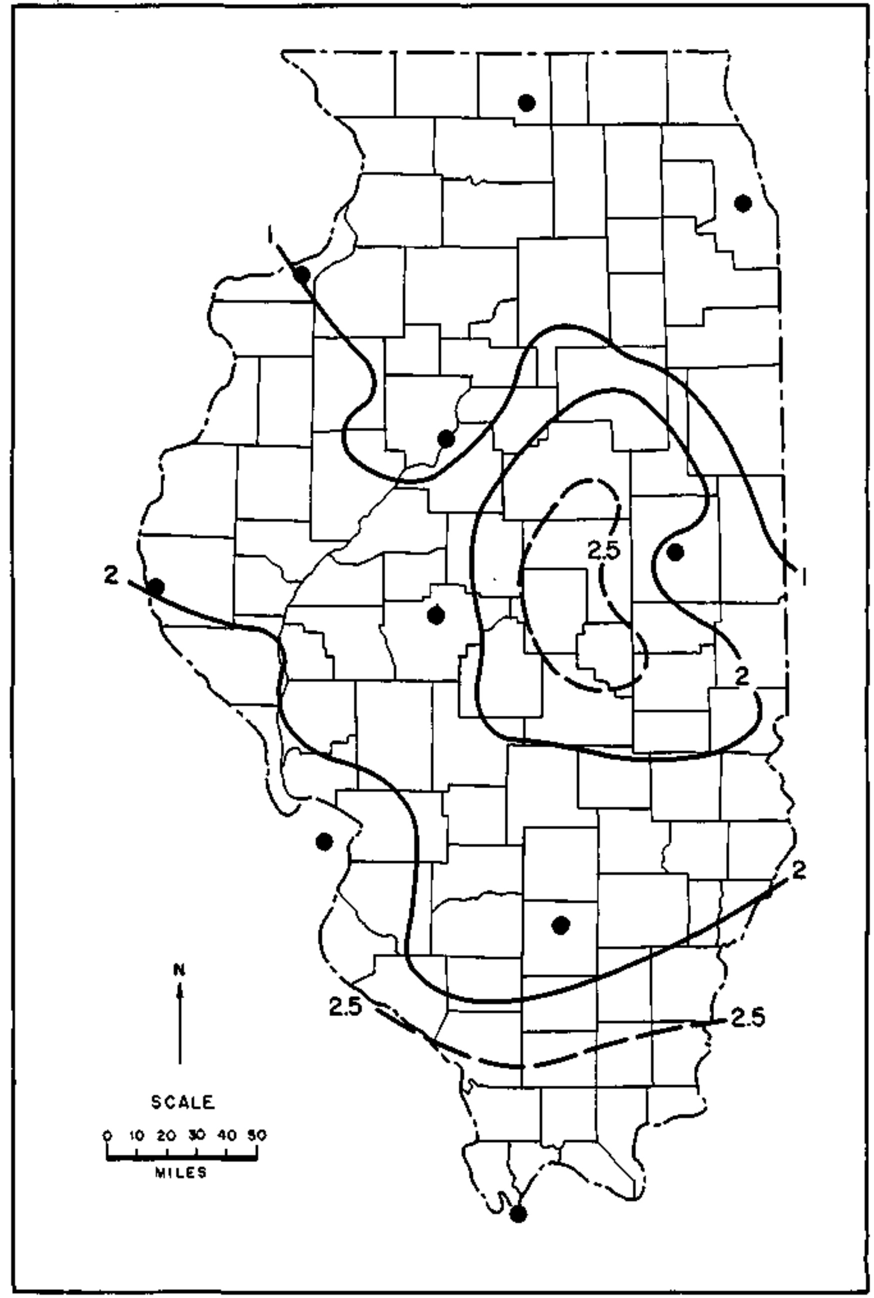


FIGURE 29 WINTER AVERAGE HAIL DISTRIBUTION EXPRESSED AS NUMBER OF DAYS WITH HAIL PER 10-YEAR PERIOD

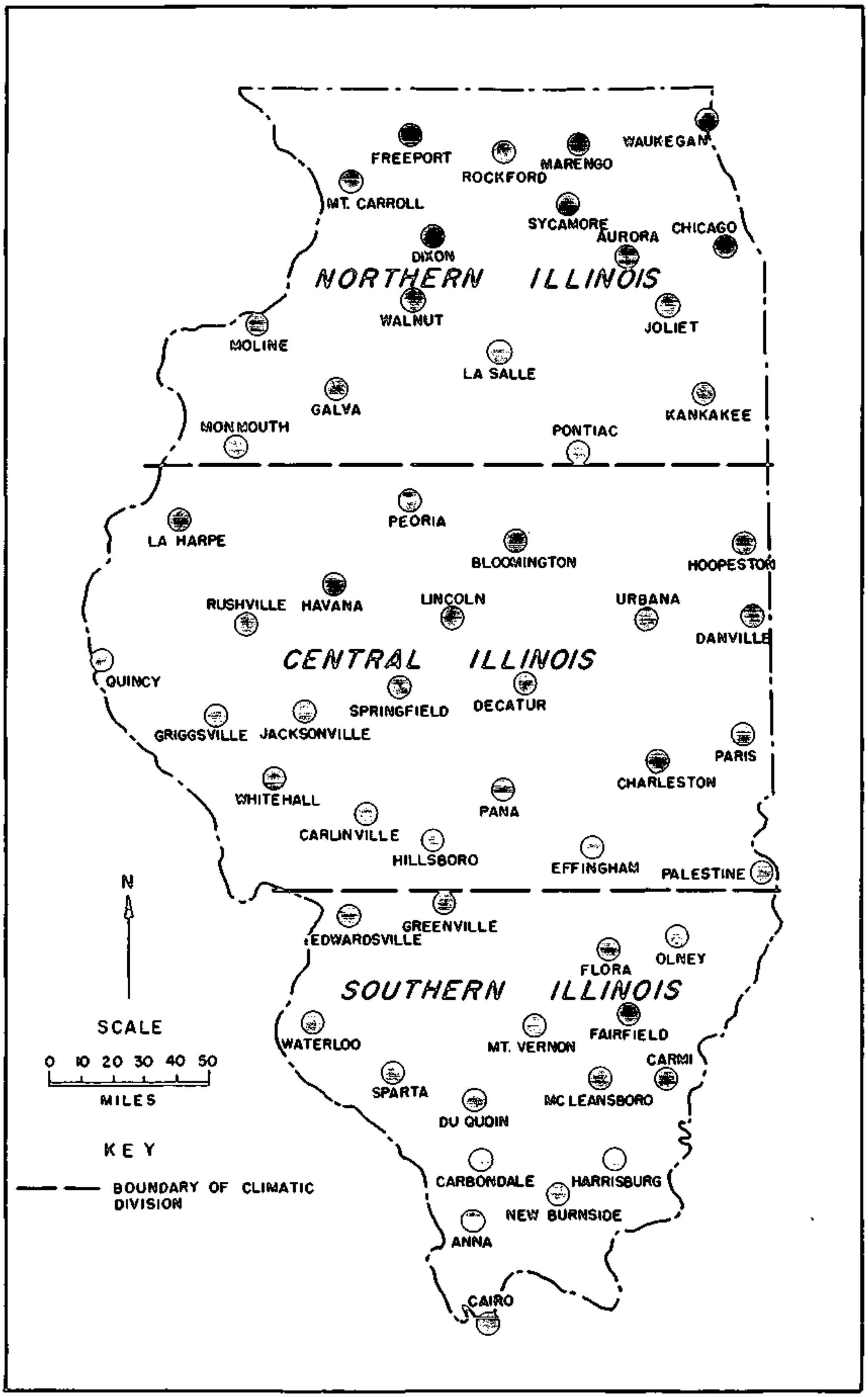


FIGURE 30 STATIONS USED FOR 1925-1948 STUDY OF DAILY HAIL AND CLIMATIC DIVISIONS OF ILLINOIS

DAILY HAIL STATISTICS

Records from 55 stations (Fig. 30) were used to make a study of the frequency of hail days and stations reporting hail. Also, the distances separating stations reporting hail on a given day of activity were investigated. Data for the 24 years from 1925 through 1948 were used in this study.

FREQUENCY OF HAIL DAYS AND HAIL REPORTS

During the 24 years, 1925 through 1948, there were 938 days, or an average of 39 days per year, when one or more of the 55 stations (Fig. 30) reported hail. As many as 63 hail days were reported in one year, 1927, and as few as 23 days in 1939. The total and average number of days with hail per month and year are shown in Table 4. May with an average of almost eight days of hail per year has the highest number, followed by April with approximately six days and March and June with between five and six days.

During the 24 years, the 55 stations had a combined total of 1,712 separate reports of days with hail, almost twice as many as the number of hail days. Actually, 698 of the 938 days with hail, or 74 percent, resulted from cases of only one station in Illinois reporting hail on a given day. Therefore, on the remaining 240 days of hail there were 1,014 station reports of hail. That is, 59 percent of the hail reports occurred on only 26 percent of the days with hail in the 24-year period.

Table 4 gives the total and average number of hail reports per month and year. May is indicated as highest with an average of almost 16 reports per year, followed by April and March with approximately 13 each and June with 9 reports. May has had as many as 48 reports of hail in one year, 1933, and as many as 16 days of hail, 1927. Conversely, there were neither days of hail nor reports of hail in May 1939. The maximum and minimum number of hail reports and hail days for each month from 1925 through 1948 are shown also in Table 4.

A ratio of the number of hail days per month to the number of hail reports per month is shown in Table 4. The lower the ratio, the more frequent are the cases of multiple hail reports on single days of hail. The three lowest ratios are reached in March, April, and May. The winter months have high ratios, indicating that on winter hail days very few stations report hail. July, August, and September also have high ratios which are comparable to those of the winter months. These ratios indicate that many middle and late summer hailstorms extend over a relatively small area.

To investigate further the number of hail reports on a given day, hail days were classified as having 1, 2, 3, 4, 5, and 6 or more reports per day. Then, the number of reports in each of these daily classifications was evaluated as a percent of the total monthly reports. These values are shown in Table 5.

TABLE 4

MONTHLY AND ANNUAL NUMBER OF HAIL DAYS AND HAIL REPORTS FROM 55 STATIONS, 1925 THROUGH 1948

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Frequency of Hail Reports													
Total number of reports	32	65	304	314	377	211	135	92	45	61	63	13	1712
Average number per year	1.3	2.7	12.7	13.1	15.7	8.8	5.6	3.8	1.9	2.5	2.6	0.5	71.2
Maximum hail reports in one year	6	14	38	36	48	21	14	11	12	8	10	4	128
Minimum hail reports in one year	0	0	1	4	0	1	0	0	0	0	0	0	44
Frequency of Hail Days													
Total number of days	27	42	129	142	182	130	91	70	35	41	39	10	938
Average number per year	1.1	1.8	5.4	5.9	7.6	5.4	3.8	2.9	1.5	1.7	1.6	0.4	39.1
Maximum number in one year	4	5	12	12	16	11	10	7	4	4	4	2	63
Minimum number in one year	0	0	1	2	0	1	0	0	0	0	0	0	23
Ratio-- Hail days/ Hail reports	0.84	0.65	0.42	0.45	0.49	0.62	0.67	0.76	0.78	0.67	0.62	0.77	0.55

TABLE 5

PERCENT OF MONTHLY AND ANNUAL HAIL REPORTS RESULTING FROM DAYS WITH 1 TO 6 OR MORE REPORTS, 1925 THROUGH 1948

	Percent of Total Hail Reports												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1 Report Per Day	72	46	34	28	28	44	48	63	67	84	64	62	41
2 Reports Per Day	19	19	11	17	23	23	27	22	13	6	25	15	19
3 Reports Per Day	9	14	9	19	21	19	13	10	20	10	5	23	15
4 Reports Per Day	0	6	11	10	4	9	12	0	0	0	6	0	7
5 Reports Per Day	0	15	8	10	8	2	0	5	0	0	0	0	6
6 or More Reports Per Day	0	0	27	16	16	3	0	0	0	0	0	0	12

TABLE 6

DISTANCES BETWEEN HAIL REPORTS IN MILES

Based on Data for 1925 Through 1948 from 55 Stations

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Two Stations Reporting													
Average Distance	39	44	130	112	83	108	99	140	64	51	78	--	95
Maximum Distance	227	55	242	280	221	279	228	319	77	78	108	104	319
Minimum Distance	46	25	25	25	18	36	20	31	53	25	37	--	18
Number of Cases	3	6	17	26	43	24	18	10	3	2	8	1	161
Three Stations Reporting													
Average Max. Distance	--	120	176	148	147	144	91	155	85	90	--	--	128
Longest Distance	81	176	321	319	316	237	182	275	99	145	80	180	321
Average Min. Distance	--	40	58	48	55	59	38	73	33	39	--	--	49
Shortest Distance	38	26	23	21	21	20	20	27	24	25	60	33	20
Number of Cases	1	3	9	20	26	13	6	3	3	2	1	1	88
Four Stations Reporting													
Average Max. Distance	--	--	183	206	168	140	122	--	--	--	--	--	164
Longest Distance	--	83	323	280	230	203	159	--	--	--	188	--	323
Average Min. Distance	--	--	43	45	53	33	37	--	--	--	--	--	42
Shortest Distance	--	26	21	23	25	20	20	--	--	--	61	--	20
Number of Cases	--	1	8	8	4	5	4	0	0	0	1	0	31
Five Stations Reporting													
Average Max. Distance	--	154	183	202	182	--	--	--	--	--	--	--	180
Longest Distance	--	214	230	298	330	218	--	163	--	--	--	--	330
Average Min. Distance	--	29	29	32	35	--	--	--	--	--	--	--	31
Shortest Distance	--	19	20	24	20	40	--	35	--	--	--	--	19
Number of Cases	0	2	5	6	6	1	0	1	0	0	0	0	21
Six or More Stations Reporting													
Average Max. Distance	--	--	213	208	190	--	--	--	--	--	--	--	204
Longest Distance	--	--	321	330	346	166	--	--	--	--	--	--	346
Average Min. Distance	--	--	31	27	26	--	--	--	--	--	--	--	28
Shortest Distance	--	--	18	23	18	23	--	--	--	--	--	--	18
Number of Cases	0	0	12	7	9	1	0	0	0	0	0	0	29

On the average, almost 41 percent of the annual hail reports are from a single station report of hail on a given date. The lowest monthly percent attributed to only one hail report per day occurs in May. April and March rank second and third lowest, respectively. January, September, and October have the highest percentages of hail days with single reports. For days with only two reports of hail, July has the highest monthly percentage, 27. October and March have the lowest percentages for two reports per day. Annually, 19 percent of all reports are from cases with two reports per day. From July through January, at least 74 percent of the reports in each month are in the classification of one or two per day, further illustrating the great predominance of days with relatively isolated instances of hail during these months.

Excluding December, when relatively few hail storms occur, May ranks highest in days with three reports with an average of 21 percent. On the average, 15 percent of the total annual reports are in the category of three reports per day.

July ranks highest in the classification of four reports per day, although March and April also have percentages greater than ten. Days with four station reports account for seven percent of the total annual hail reports.

Percentages for days with five reports and for days with six or more hail reports indicate why March has the lowest monthly ratio in Table 4. The combined percentages for these two classifications show that 35 percent of the March reports are for days with five or more reports of hail. April has 26 percent of its total reports in this category and May has 24 percent. Of the remaining nine months, only June and August have had days with five or more reports of hail.

DAILY AREAL DISTRIBUTION OF HAIL

Days with more than one report of hail were classified according to the number of reports, and the extent of hail within the state was investigated for each classification on an annual and monthly basis. For days with two reports the average distance separating the reporting stations was calculated. If more than two reports for a single day were available, the longest and shortest distances separating any two of the stations were determined for each day of activity (Table 6).

The annual average distance between stations with two reports of hail is 95 miles, as shown in Table 6. The annual average maximum distance between stations on a day when three stations report hail is 128 miles, increasing to 164 miles for cases of four reports per day, 180 miles for five reports per day, and 204 miles for six or more reports. The longest distances recorded for each classification also increase with an increase in the number of daily hail reports. The longest distance increases from 319 miles for two reports to 346 miles for six or more reports per day.

Monthly values are given also in Table 6. Very little significant difference exists between the monthly average minimum distances for each of the classifications. However, the average maximum distances reveal some interesting trends from month to month. Cases with two reports of hail have their highest average separation in August, 140 miles with a secondary high of 130 miles in March. For the other four classifications, the average maximum distance is greatest in March or April. The May average maximum distance between reports is third highest in all classifications, followed by a continuing decrease into June and July for classifications still having sufficient cases to calculate averages. August reverses this trend in diminishing distances between reports, as an increase is evident for the two-per-day and three-per-day classifications.

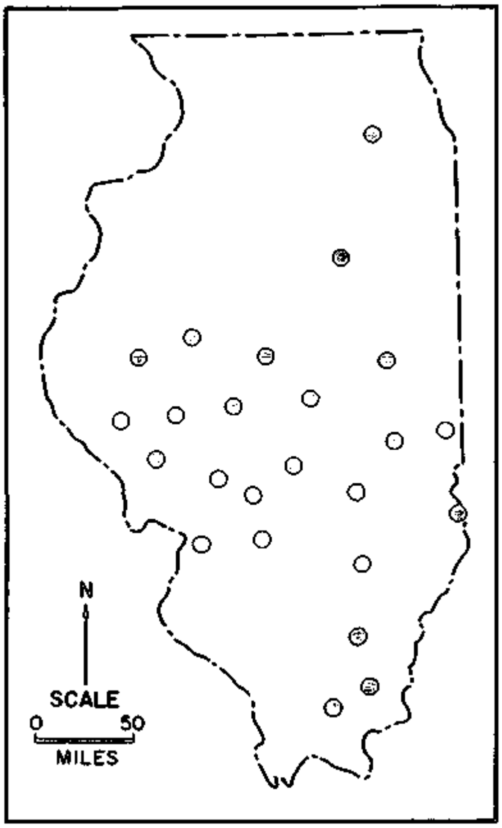
The data on areal extent of hail show that March and April have the highest percent of cases of reports of five or more per day, and they also have the highest average maximum distances between any two reports for this classification. Therefore, hail activity in Illinois on a given day in March or April is more likely to cover a greater area than in any other month. On the average, May and April have more days of hail and hail reports than March, but daily hail activity is not quite as widespread as in March.

During the 24 years under study, there were 15 days when 11 or more stations reported hail. That is, 20 percent or more of the 55 stations had hail. Of these 15 days with a maximum number of reports, nine occurred in March, three in April, and three in May. The day with the greatest number of reports occurred on March 2, 1940, when 24 of the 55 stations, or 44 percent, listed hail occurrences. These observations indicate that about 24,000 square miles of area in the state were affected by hail on that date. The stations reporting hail on this day and on the days with the second, third, and fourth highest number of reports in this 24-year period are shown in Figure 31. Further description of these 'our storms is given in Table 7. The maps in Figure 31 give some indication of the possible areal extent of hail activity in Illinois on a single day in spring.

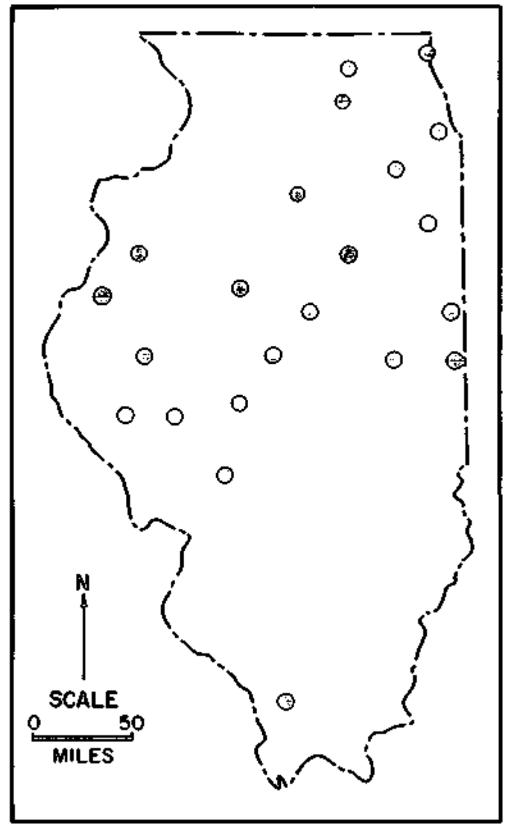
METEOROLOGICAL CONDITIONS ASSOCIATED WITH WIDESPREAD HAILSTORMS

An investigation was made of synoptic weather conditions associated with the most widespread hailstorms during the 24-year period, 1925through 1948. The 24 days having the greatest number of hail reports during this period were used to represent the 24 most widespread storms. A tabulated summary, showing rainfall area-depth relations for each storm, number of hail reports, location of hail, and synoptic weather type, is given in Table 7. North, central, and south, as indicated in the table, refer to the U. S. Weather Bureau state climatological divisions(5) which are shown in Figure 30.

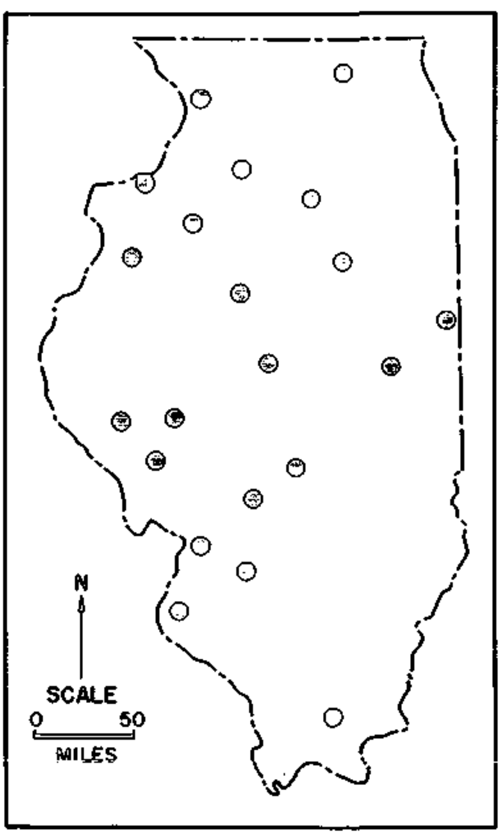
Table 7 indicates that 23 out of the 24 days with the most hail reports occurred during the three spring months. Moreover, 20 of the days occurred in the 63-day period from March 2 through May 3. Of the 24 days, eleven occurred in March, six in April, six in May, and one in



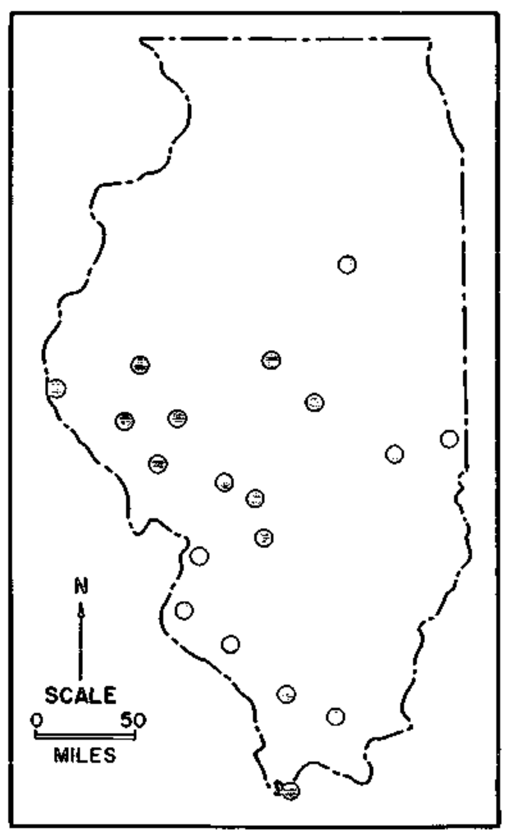
a. MARCH 2,1940, 24 REPORTS



b. MARCH 16,1942, 22 REPORTS



c. APRIL 4,1927, 21 REPORTS



d. MARCH 21,1932, 19 REPORTS

FIGURE 31 HAIL DISTRIBUTION ON FOUR DAYS WITH MAXIMUM NUMBER OF REPORTS IN 1925-1948 PERIOD

June. None occurred in July and August when the major crops in Illinois are most susceptible to hail damage. Most of the annual hail (57 percent) occurs in the March through May period.

Classification of synoptic weather conditions was done by use of printed northern hemisphere maps available in the University of Illinois Library. This classification indicated that three of the twenty-four hail days occurred with the approach and passage of low centers, eight with low centers and associated warm fronts, one with a warm front, eleven with cold fronts, and one with cold-type occlusion.

Grouping the synoptic types by month showed that seven out of eleven March hail days occurred with low centers and associated warm fronts and three with cold fronts. In April, five out of the six storm days were associated with cold fronts. In May there was no dominant synoptic type.

In general, it was observed that these extensive hailstorms were associated with strong synoptic systems which had pronounced frontal contrasts and relatively strong surface winds. The hail distribution patterns were generally typical of the associated synoptic system. Line patterns with orientations approximately north-south to northeast-southwest were generally associated with cold fronts, while broader patterns approaching orientations of west-east usually accompanied the low and warm front situations.

Of the 24 hailstorms, ten spanned only the north and central sections of the state, seven were confined to the south and central sections, and seven were widespread over the state. Since more than one area of the state reported hail in each storm, as shown in Table 7, the area of maximum number of reports was listed first with areas of fewer reports following in descending order. In all 24 storms, hail fell in some portions of central Illinois. In March, only five out of eleven hailstorm days produced hail in the northern section of the state, while all caused hail in the central section and nine produced hail in the south. Northern Illinois received hail in five out of the six April storm days. Of the six May storms, only two affected southern Illinois,

TABLE 7

RELATION OF 24 MOST WIDESPREAD HAILSTORMS WITH RAINFALL AND OTHER FACTORS

Date	Depth (in.) for Given Area (sq. mi.) 1000	5000	10,000	20,000	No. of Hail Reports	Synoptic Type[1]	Location of Reports[2]	Monthly Mean Rainfall (in.)	Percent of Monthly Mean Rainfall at Given Area (sq. mi.) 1000	20,000
3/2/40	1.8	1.7	1.5	1.3	24	WL	CS	2.9	62	45
3/16/42	3.1	2.3	1.8	1.4	22	WL	CNS	2.9	107	48
4/4/27	2.4	1.6	1.3	1.0	21	C	NCS	3.8	63	27
3/21/32	1.3	1.2	1.1	0.9	19	WL	CS	2.6	50	35
4/23/44	5.9	4.7	4.0	3.2	16	C	NC	3.8	158	84
4/19/27	2.4	2.0	1.9	1.6	15	C	CN	3.4	54	47
3/20/35	1.3	1.0	0.9	-	14	O	CN	2.8	46	-
3/11/39	4.8	4.3	3.9	3.3	13	WL	CS	3.3	145	100
5/3/37	1.8	1.3	1.0	-	12	L	CSN	4.1	44	-
3/16/43	2.6	2.2	2.0	1.7	12	C	CSN	3.1	84	55
3/30/38	5.1	4.0	3.3	2.6	12	C	CS	3.7	138	70
3/15/38	4.7	3.5	2.8	2.2	12	WL	CNS	3.6	131	61
3/22/38	2.2	1.9	1.6	1.4	11	C	CN	2.9	76	48
5/9/27	3.1	2.6	2.4	2.1	11	C	NC	4.1	76	51
5/1/33	1.8	1.5	1.3	1.0	11	L	CN	3.9	46	26
5/11/33	4.0	2.9	2.3	1.8	10	W	CN	4.0	100	45
3/29/28	2.0	1.5	1.1	-	10	WL	CS	3.7	54	-
4/30/33	1.3	1.2	1.2	1.0	10	C	NC	3.2	41	31
4/10/33	1.4	0.9	-	-	10	C	NCS	2.8	50	-
3/25/35	2.9	2.2	1.7	1.4	10	WL	CS	3.7	78	48
4/9/43	1.3	1.2	1.0	-	9	L	CS	3.9	33	-
5/1/36	3.7	2.7	2.2	1.7	9	C	CN	4.0	93	43
5/24/46	4.5	2.8	1.9	-	9	C	NSC	4.0	113	-
6/12/29	4.9	4.0	3.4	2.7	9	WL	NC	4.0	123	68

[1]Synoptic types associated with hail day:
C = cold front, W = warm front, L = low, WL = warm front and connected low, and O = occlusion.

[2]Location of hail reports in Illinois by three areas:
N = northern, C = central, and S = southern.

and these occurred on days when hail was recorded throughout the state.

The preceding statistics indicate a trend for the more extensive hailstorms to occur over the south and central parts of the state in March, and over the north and central portions in April and May. In 23 of the 24 storms investigated, hail was recorded within the region of maximum hail frequency in southwest central Illinois (Fig. 2). This region appears to lie frequently within the path of low pressure systems and warm fronts in spring and, also, in the southern portion of hail bands produced by the approach and passage of cold fronts during the spring.

Relation of Hail to Rainfall

Reference to the rainfall summary in Table 7 indicates that relatively heavy rainfall usually occurs in the state during periods of extensive hail. The rainstorm area-depth relations show that in 42 percent of the storms mean rainfall exceeded three inches over 1000 square miles, while in 54 percent of the storms the mean rainfall exceeded two inches over 5000 square miles. In 71 percent of the storms, mean rainfall exceeded one inch over 20,000 square miles or 35 percent of the state. It was found that the major portion of the hail occurred within the rainstorm core in most instances. Some of the individual rainstorms which occurred in conjunction with the widespread hailstorms were exceptionally heavy. For example, other studies being conducted at the Water Survey indicate that a storm having mean rainfall exceeding three inches over 20,000 square miles occurs only once in two years on an average in the entire state of Illinois. The storms of March 29, 1939 and April 23, 1944 both exceeded the two-year recurrence value for 20,000 square miles.

Columns 9 to 11 in Table 7 show the monthly mean rainfall within the area of each storm and the percentage of the monthly rainfall which fell in each storm over areas of 1000 and 20,000 square miles. These columns provide another measure of the magnitude of the rainstorms and permit an evaluation of the relative severity of these storms in each month. The relative severity of the rainstorms remains approximately constant at 20,000 square miles as the warm season advances, while it tends to increase at 1000 square miles. Using the data presented in Columns 10 and 11, it was found that the median percentage of monthly mean rainfall at 20,000 square miles for March and April storms is 48 compared to 45 for May and June storms. At 1000 square miles, the median is 63 percent in March and April storms and increases to 93 percent for May and June storms. Thus, the data indicate that the rainfall intensifies at storm cores as summer approaches, but that the areal extent of the storms does not increase, as would be expected from climatological considerations.

Location of Hail Reports

Analysis of the location of the hail reports for these 24 hailstorm days was conducted to ascertain where the hail occurred in respect to the heavy rainfall cores. For these 24 storms there were 311 reports of hail. Sixty-three percent, or 196 of the 311 reports came from stations located within the rainfall core or cores. Nineteen percent of the reports were from locations south of the cores, eleven percent were located to the north, four percent were to the west, and three percent of the reports lay between heavy rainfall cores.

The 24 storms were divided according to synoptic types. Data from twelve of these storms, eleven cold front and one cold-type occlusion, were grouped and compared with data from the twelve storms associated with warm fronts and lows. The 12 storms associated with the cold fronts and occlusion produced 150 of the 311 reports. Fifty-eight percent of these 150 reports were located within the storm core, while 19 percent were to the north, 16 percent to the south, 5 percent to the west, and 2 percent occurred between rainfall cores. The remaining 161 reports were associated with warm fronts and low passages. Sixty-eight percent of these 161 reports were within the high rainfall cores of the storms, 23 percent were to the south, 3 percent were to the west, 3 percent to the north, and 3 percent lay between cores.

This comparison revealed that in extensive hailstorms associated with lows and warm front passages, the hail occurred more frequently in the high rainfall areas than it did with cold front passages. The most significant difference between the general location of hail occurrences associated with the different synoptic types was the frequency of occurrence of reports on the north and south sides of the rainfall cores. Only three percent of the reports occurred to the north of a core when warm fronts and/or lows occurred, while 19 percent of the reports from cold fronts lay to the north of the cores. Conversely, the warm fronts and lows had a greater percentage of their reports on the south side of the cores than did the cold fronts. Seventy-seven percent of the cold front reports were in the core and to the north, while 91 percent of the warm front-low reports were in the core and to the south of it. Most of the cold fronts moved from the west or northwest, and most of the lows and warm fronts moved from the south and southwest.

Diurnally, heavy rainfall in Illinois tends to develop later in the day than hail. The preponderance of hail in and to the south of the rainfall core with warm fronts and/or lows is in agreement with this diurnal trend. Although the agreement is not as striking with cold fronts, 82 percent of the hail occurred in the rainfall core or north and west of it.

Rainfall Amounts at Hail Reporting Stations

The actual amount of rainfall occurring at stations reporting hail in the 24 extensive hailstorms was determined. The average station rainfall based on the 311 station amounts was 1.16 inches and the median value was 0.91 inch. Eighteen of the 311 values were three inches or more while 29 were in the range from 2.00 to 2.99 inches. Ninety-six values were in the range from 1.00 to 1.99 inches while 168 values, or 54 percent, were less than one inch.

Similar statistics were compiled for data from the different synoptic types. Rainfall from the 150 stations reporting hail in the 12 storms associated with cold fronts and cold-type occlusion averages 1.20 inches, only slightly more than the 1.11-inch average from stations with hail associated with warm fronts and lows. The cold front storms produced more individual amounts in the range from 1.00 to 1.99 inches and in the greater than 3-inch category, while the storms associated with warm fronts and lows had more rainfall amounts in the range from 2.00 to 2.99 inches and in the less than 1-inch category.

These data also were studied on a seasonal basis. The average rainfall at the 177 hail-reporting stations associated with the twelve earliest storms, the eleven in March and the first in April (April 4, 1927), was 1.08 inches. The later twelve storms, those in June and May plus the last five in April, had 134 of the 311 hail reports and the average rainfall at these stations was 1.25 inches.

Duration and Hourly Occurrences of Hail Periods

The time of occurrence of the 311 hail reports on these 24 days was studied by classifying the hail reporting times on a hail day into one inclusive period of hail occurrence. This was done for two reasons. The individual station reports of hail times were grouped because the hail on days with widespread activity did not occur instantaneously and the reporting times covered a period of several hours. Secondly, the grouping into a single period was necessary for most storms so that the problem of missing data could be overcome. Many of the stations did not report the time of occurrence, and an accurate sampling of all times of occurrence could not be obtained. This method did enable a fairly accurate determination of the period in which all of the hail reports had occurred. For instance, if the first hail report on a day was 1:15 P.M. and the last at 3:45 P.M., the duration of the hail period was 2.5 hours, and an hourly occurrence for hail was recorded for 1 to 2 P.M., 2 to 3 P.M., and 3 to 4 P.M.

Several of the storm days exhibited more than one general period of hail occurrences. If these periods were separated in time by four or more hours, they were considered separate periods. Ten of the 24 storm days had two hail periods; thus, a total of 34 hail periods occurred during the 24 storm days. Five of the days with two hail periods were associated with warm front and/or lows, four with cold fronts, and one with an occlusion.

The occurrence of two periods of hail on a single day suggested the presence of at least two different hail-producing synoptic situations during the day. Interestingly, seven of the ten cases occurred in the eleven March storms, and two of the remaining three cases occurred in early April.

The average duration of these 34 hail periods was 3.3 hours with a maximum duration for one period of eight hours and a minimum of 0.4 hour. The durations were analyzed also by synoptic types and by hours of occurrence in the day. The average duration of the 17 warm front-low pressure type of storms was 3.7 hours compared to an average of 2.9 hours for the 17 storm periods associated with cold fronts. The 15 periods that occurred in the 12 hours from midnight to noon had an average duration of 3.3 hours, while 19 periods in the 12 hours from noon to midnight had an average duration of 3.2 hours. Thus, there was no significant difference in durations between storms in the morning and afternoon.

The diurnal distribution of the hail reports was computed from the hail periods by counting an hourly occurrence for each hour between the beginning and ending times of each report, as explained previously. The 34 storm periods produced hail in 127 hours. The maximum hourly number was 13 recorded for 4 to 5 P.M. The maximum three-hour period was 2 to 5 P.M. and had 28 percent of the total hourly occurrences. A slight secondary maximum occurred from 5 to 8 A.M. The maximum six-hour period extended from 1 to 7 P.M. and had 46 percent of the total occurrences.

The hourly occurrences were divided according to the two basic synoptic types involved in this analysis. The maximum three-hour and six-hour periods for both types were 2 to 5 P.M. and 1 to 7 P.M., respectively. There was less agreement between the hourly occurrence data for the morning hours. Forty-two percent of the 69 hourly reports with warm front-low pressure conditions occurred before noon, as compared to 40 percent of the 58 cold front hourly occurrences in these 12 hours. The maximum three-hour period from midnight to noon for the warm front-low pressure occurrences was 5 to 8 A.M., while for the cold front data it was 9 A.M. to noon.

Hailstone Intensities

By utilizing U. S. Weather Bureau First-Order and substation records of hail, the hail intensities from the 311 hail reports of the 24 extensive storms were analyzed. Weather Bureau observers classify hail as light, moderate, or heavy depending on the intensity. A light intensity was recorded when only a few pellets fell, moderate for a higher rate of fall and with some accumulation of stones on the ground, and heavy when hail falls rapidly with a large accumulation on the ground. Because the intensities reported in one storm often varied, in classifying each storm, two new categories -- light to moderate and light to heavy -- were added. Nine of the 24 storms had light intensities only, one had only moderate, and two had only heavy intensities. Of the remaining 12 storms, five were in the light to moderate category and seven had intensities ranging from light to heavy. Nine of the 24 storms had at least some reports of heavy hail and 15 of them had some reports of moderate hail. Light hail occurred in 21 of the 24 storms. As expected, on all nine of the days having heavy intensities of hail, hail damage to property was experienced in Illinois.

Seasonally, four of nine storms with heavy hailstone intensities came in March, three in April, and two in May. Only three of the eleven

March storms had intensities restricted to light and eight had moderate intensities. There was no great seasonal variation in the moderate and heavy intensities, but six of the last eleven storms had reports of only light intensity, as compared to three in the thirteen storms occurring earlier in the season.

Damages from Hailstorms

The dollar damages resulting from hailstorms occurring on the 24 days of most widespread hailstorms in the 1925 through 1948 period were obtained from U. S. Weather Bureau records. A few minor injuries were suffered by persons, but no deaths resulted from hail. Thirteen of the storms produced some amount of recorded property damages from the hail, but only six of these had more than $50,000 in damages. Only two storms (April 9, 1943 and April 4, 1927) resulted in appreciable damages, $206,000 and $155,000, respectively. The total damages from the 13 hailstorms was $775,000. Nine of the 13 storms producing damages were associated with warm front-low pressure situations and eight of the earliest 12 storms produced hail damage.

Nine of 13 damaging hailstorm days had some reports of heavy hail intensities and three of the remaining four cases had moderate hail. One storm, on June 12, 1929 with $5,000 damages, had only light hail. Nine of the 13 storms with heavy and moderate intensities also had simultaneous reports of light hail. Eight of 13 days under discussion had tornadoes. Only three of the 11 hailstorm days with tornadoes did not have hail damages. In addition eight of 13 days had associated wind damages in addition to the tornado damages.

Severe Weather

On many of the 24 days under analysis, other forms of severe weather occurred, such as tornadoes, windstorms, and lightning. Eleven of the 24 days had tornadoes, 13 had damaging winds, and 6 had damages from lightning.

On the 11 hail days with tornadoes, a total of 34 tornadoes was recorded. These 34 were approximately 30 percent of the total 118 tornadoes that occurred in Illinois in the 1925 to 1948 period.[6] Moreover, the two days in this period with the highest number of tornadoes were March 30, 1938, with nine, and May 9, 1927, with seven. These were also two of the 24 most extensive hail days. In addition, eight of the eleven tornado days associated with the extensive hail days were classified as destructive.[6] To be classified destructive, the tornadoes must have produced $50,000 or more in property damages and killed at least one person. These eight days included one-fifth of all the destructive tornadoes that occurred in Illinois during this period.

The 34 tornadoes associated with the extensive hailstorms killed 78 persons, injured 667, and caused $5,497,000 in property damages. Twenty-one of the tornadoes were associated with the earliest 12 hail days. Tornadoes occurred on seven of these first 12 days compared to only four in the last 12 days. As expected, a greater proportion of the damages, injuries, and deaths resulted from the tornadoes that occurred in the first 12 storms. In only two of the 11 tornado-hail days were the hail intensities less than moderate, further illustrating the tremendous strength of the synoptic systems associated with many of the days of extensive hailstorms. All four of the most extensive hailstorm days (Fig. 31) had tornadoes plus wind or lightning damages.

The total damages resulting from windstorms on the 24 hail days was $2,005,000 in property damages and two deaths. Associated lightning produced $38,000 in damages and killed three persons. The grand total of property damages from hail and other severe weather phenomena on these 24 days was $8,315,000 or approximately $347,000 per storm. The total number of deaths was 83, and 667 persons were injured.

DIURNAL DISTRIBUTION OF HAIL

As pointed out earlier, the hail records of the U. S. Weather Bureau cooperative substations frequently did not list the time of hail occurrences. Thus, an accurate sampling of the diurnal distribution could not be obtained from this source. However, time of occurrence of hail was available from hail insurance records in Illinois for 1948 through 1957.(7) Suitable data were availa-

TABLE 8

DIURNAL DISTRIBUTION OF HAIL

		Starting Time (CST) of Maximum Period and Percent of Total Hours in Period									
Period	Total Number of Hail Hours	1-hour Time	Maximum Percent	2-hour Time	Maximum Percent	3-hour Time	Maximum Percent	6-hour Time	Maximum Percent	12-hour Time	Maximum Percent
May	238	3:30 PM	10.9	3:30 PM	20.1	2:30 PM	28.5	2:30 PM	45.6	11:30 AM	72.5
June	663	3:30 PM	9.2	2:30 PM	17.8	2:30 PM	26.1	1:30 PM	48.4	11:30 AM	76.3
July	677	4:30 PM	8.7	3:30 PM	16.2	2:30 PM	24.2	2:30 PM	42.2	11:30 AM	67.8
Aug.	452	2:30 PM	9.5	2:30 PM	18.1	2:30 PM	26.3	2:30 PM	47.4	12:30 PM	74.3
Sept.	298	4:30 PM	9.4	4:30 PM	18.5	2:30 PM	26.2	1:30 PM	48.7	11:30 AM	72.9
Oct.	71	1:30 PM	12.7	1:30 PM	22.6	1:30 PM	33.9	1:30 PM	47.9	9:30 AM	67.5
May-Oct.	2399	3:30 PM	8.7	2:30 PM	17.3	2:30 PM	26.0	1:30 PM	46.1	11:30 AM	72.4

ble in these insurance records for the months May through October, but, unfortunately, the records included very little statistical data for March and April, two of the months of heavy hail occurrence. This lack of data is to be expected in crop-hail insurance records, since relatively little crop.damage from hail occurs in the early spring in Illinois. Another limiting factor of the hail insurance data is that most of the ten years of data was collected from reports in northern and central Illinois. There was very little hail insurance coverage in southern Illinois. However, it is believed that the insurance statistics on the diurnal distribution of hail are representative of conditions in Illinois despite the data limitations described above.

Days with fewer than five paid hail losses were omitted from the analysis to eliminate entries due to observational errors and days with insignificant hail activity. Otherwise, each day of hail losses was examined and each hour during that day on which one or more hail losses occurred was recorded as an hour with hail. No distinction was made between the number of losses in each hour on a particular hail day. Thus, if 25 losses occurred at 3:00 P.M. and 50 losses at 4:00 P.M. on a certain day, only one entry would be made on the tabulation sheet for each of these hours. Due to the data source, the analysis was necessarily restricted to data for damaging hailstorms.

The diurnal hail distribution for Illinois from 1948 through 1957, as indicated by the hail insurance data, is summarized in Table 8 by months and for the May through October period. Column 2 shows the total number of hours with hail for each month. The 1-hour, 2-hour, 3-hour, 6-hour, and 12-hour periods having the most frequent occurrences of hail and the percent of the total number of hail hours observed during each of these maximum periods is given in columns 3 through 12. Table 8 shows the maximum frequency of hail to be from early afternoon to early evening throughout the May through October period. This agrees with findings concerning the hourly occurrences of the 24 most extensive hailstorms in the 1925 through 1948 period. Combining the six months, the hour of maximum occurrence was 3:30 P.M. to 4:30 P.M. during the 1948 through 1957 period. However, differences between this hour and the hour preceding and following were insignificant, as shown by the percent of total hail hours for the 2-hour and 3-hour maximum periods beginning at 2:30 P.M. Table 8 shows that during the May through October period 8.7, 17.3, 26.0, and 46.1 percent of the total hail hours occur within the maximum 1-hour, 2-hour, 3-hour, and 6-hour periods, respectively. If hail were distributed uniformly throughout the day, the percentages would be 4.2, 8.3, 12.5, and 25.0 for these hourly periods, respectively. Thus, the maximum one-hour period includes more than double the occurrences to be expected during an average hourly period, while the maximum six-hour period, 1:30 P.M. to 7:30 P.M., includes nearly double the average six-hour frequency.

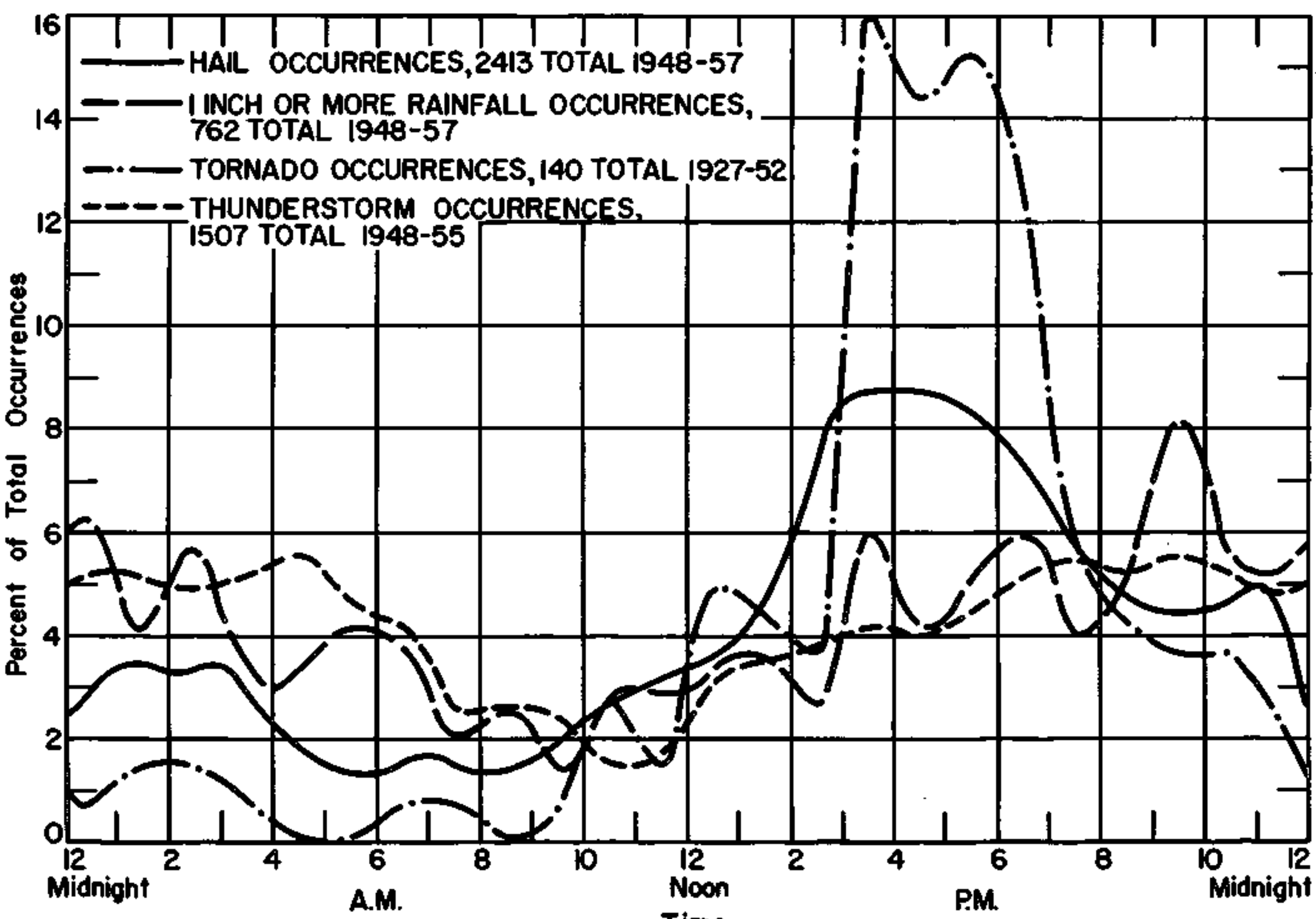


FIGURE 32 DIURNAL DISTRIBUTION OF HAIL, THUNDERSTORM, TORNADO, AND HEAVY RAINFALL OCCURRENCES

The times of maximum frequency of hail found in the Illinois study compare favorably with those of Beckwith,[8] based upon an observational network operated in the Denver area during 1949 through 1955. Percentages of total occurrences, however, differ considerably between the two locations, as might be expected considering climatic and topographic differences between the two areas and that the Illinois data include only damaging hailstorms.

The diurnal distribution of tornadoes in Illinois is very similar to that of hail, as illustrated in Figure 32. During 1927 through 1952, 140 tornadoes occurred in Illinois.[6] The maximum one-hour period was 3:00 P.M. to 4:00 P.M. when 16 percent of the total number occurred. During the maximum three-hour period, 3:00 P.M. to 6:00 P.M., 40 percent of the total number was observed. From 3:00 P.M. to 9:00 P.M., 67 percent of the total occurred. The strong diurnal maxima during afternoon and early evening for both hailstorms and tornadoes indicate that diurnal heating is an outstanding initiation mechanism for both. The slight secondary maxima during the early morning (Fig. 32) were apparently associated with the Midwest nocturnal thunderstorm phenomena.[4]

Examination of the hourly occurrences of thunderstorms at Springfield and Moline from 1948 through 1955 indicates that the diurnal maximum occurs later than the maxima of hailstorms and tornadoes (Fig. 32). The maximum three-hour period was found to be 7:00 P.M. to 10:00 P.M. with 16 percent of the total cases, while the maximum six-hour period, 7:00 P.M. to 1:00 A.M., had 31 percent of the total storms.

An analysis of hourly rainfall amounts exceeding one inch at all Illinois recording rain gage stations during 1948 through 1957 revealed a nocturnal maximizing of these rainfall heavy intensities. The results indicate that the rainfall diurnal peak occurs somewhat later than the thunderstorm maximum (Fig. 32). The maximum one-hour period was found to be 9:00 P.M. to 10:00 P.M. with eight percent of the total cases or approximately double the average hourly number that would occur with a uniform distribution. Similarly, a three-hour maximum which included 19 percent of the total cases was indicated from 9:00 P.M. to midnight, while the six-hour peak from 9:00 P.M. to 3:00 A.M. included 34 percent of the total storms.

Analysis of cloud distributions[9] over Illinois reveals that during the warm season a diurnal maximum of cumulus occurs in the early afternoon. Cumulonimbus and cirrus show a late afternoon and early evening peak during the warmer half-year. Stratocumulus and middle clouds have an early forenoon primary maxima, followed by secondary diurnal maxima in the late afternoon and evening during the warm season.

The diurnal cloud distributions -- when taken into consideration with the diurnal distribution of hailstorms, tornadoes, thunderstorms, and heavy rainfall -- suggest a logical sequence in the development and sustainment of convection systems. Cumulus, characteristic of the early development stage of convection systems, maximize in the early afternoon near the time of maximum diurnal surface heating. Hailstorms and tornadoes are associated usually with relatively violent convection. Other factors being equal, violent convection would occur most frequently during the afternoon hours when it receives its maximum support from diurnal heating. Heavy, sustained rainfall intensities are most likely to occur in Illinois with well-developed, widespread convection systems (squall zones) indicative of a strong, sustained flow of moist air into the storm zone. The maximizing of cumulonimbus, middle, and high clouds during late afternoon and early evening is indicative of the time required for development of extensive convection systems, after earlier initiation by cumulus. The maximizing of the thunderstorm frequency during the evening followed by a peak in heavy rainfall intensities would form a logical sequence as the convection systems mature. Whether hail, tornadoes, and heavy rainfall occur on the same day is dependent upon various other synoptic conditions, for example, the availability of moisture to support heavy sustained rainfall or appropriate thermodynamic conditions for the release of violent convection when aided by surface heating.

An outstanding example of the sequential occurrence of all three types of storms on one day occurred on June 14, 1957. On this day, one tornado traveled through the Springfield area in central Illinois at 2 P.M. and another occurred near Kankakee in the northeastern part of the state at 3 P.M. On the same afternoon, hail was widespread over northern and central Illinois, most of it occurring between 2:30 P.M. and 4:30 P.M. according to Crop-Hail Insurance data.[7] During the night, one of the most severe rainstorms in Illinois history took place in southwestern Illinois where rainfall amounts up to 16.5 inches were recorded in less than 12 hours with the heaviest rainfall between 11:30 P.M. and 2:30 A.M.[10] As indicated earlier in this report in the discussion of synoptic weather conditions accompanying widespread hailstorms, heavy rain and hail frequently occur on the same day.

RELATION OF HAIL TO ELEVATION

In the high plains it has been found that hail frequency increases with increasing elevation of observation points above sea level.(4) While elevations are relatively low and changes in local relief are small in Illinois compared to those farther west, it appeared desirable to analyze the Illinois hail data to determine if a correlation existed between elevation and hail frequency.

In accomplishing the elevation analysis, 80 available stations provided an approximately uniform distribution of sampling points throughout the state. The elevation of these points was then plotted against the annual hail frequency for each (Fig. 2). A similar plot was made with July-August hail data, because of the susceptibility of crops to hail damage during this period.

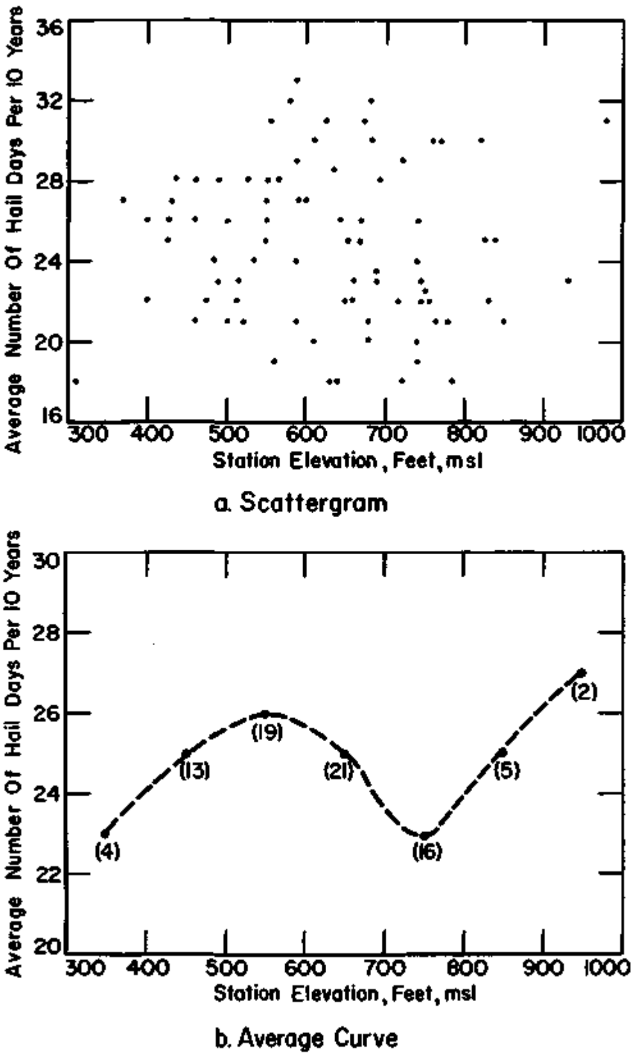


FIGURE 33 ANNUAL HAIL FREQUENCY VERSUS STATION ELEVATION

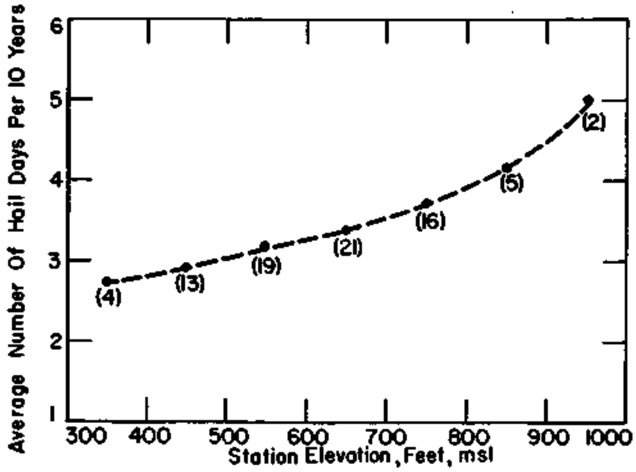


FIGURE 34 JULY-AUGUST HAIL FREQUENCY VERSUS STATION ELEVATION

Figure 33a shows a scattergram of the 80 points relating annual hail frequency to station elevation. Figure 33b shows an average curve obtained by averaging all points within each 100-foot elevation increment. The numbers at the plotted points represent the actual number of stations on which the average for each elevation increment is based. The small number of stations on which the highest and lowest elevation values are based is due to the fact that only a small portion of the state has such elevations. As mentioned previously, the sampling points were selected to provide an approximately uniform grid over the state. Figure 33 indicates that very little association exists between annual hail frequency and station elevation in Illinois.

Figure 34 shows a mean curve for the average frequency of hail in July-August plotted against elevation, similar to Figure 33b. Here, the curve indicates a slight increase in hail frequency with increasing elevation.

Figure 35 is an average curve of hail frequency versus mean temperature for the July-August period. A trend for decreasing hail frequency with increasing temperature is indicated. The highest elevations in Illinois are in the northwestern part of the state, and the July-August mean temperatures decrease northward in the state with minimum values in northwestern and northeastern Illinois. Thus, the temperature influence maximizes in the same region as the elevation and raises the question as to which, if either, is the major cause of the small changes in hail frequency shown in Figures 34-35. As pointed out earlier, the authors believe the slight increases of hail frequency in the hill regions of southern and northwestern Illinois are associated with abrupt changes in relief rather than over-all changes of elevation.

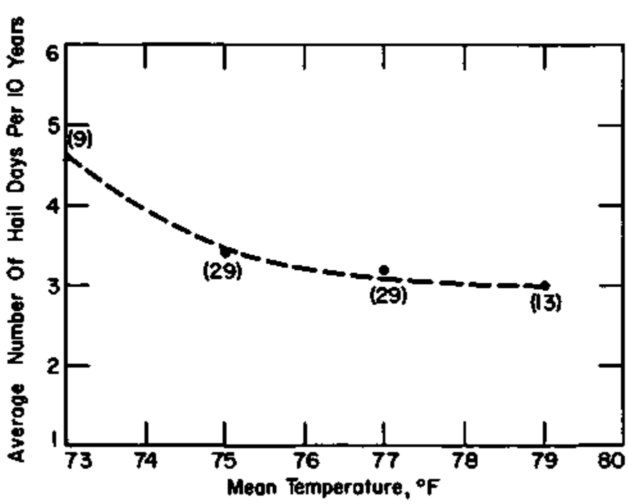


FIGURE 35 JULY-AUGUST HAIL FREQUENCY VERSUS MEAN TEMPERATURE

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