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Climatology of Severe Winter Storms in Illinois

by STANLEY A. CHANGNON, JR.

ILLINOIS STATE WATER SURVEY

URBANA

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Title: Climatology of Severe Winter Storms in Illinois.

Abstract: Severe winter storms, those producing 6 inches or more snowfall and/or damaging glaze, occur five times a year in Illinois, and cause more damage than other forms of severe weather. The climatology of all severe winter storms in 1900-1960, their damages, their synoptic weather conditions, and information applicable to design and operational considerations are presented. Storms centered most often in northwestern Illinois and averaged 6 inches of snow over 7500 square miles. Storm centers were elongated with an axial ratio of 3:1 and WSW-ENE orientations. Point snowfalls of 12 inches and glaze with a radial thickness of 2 inches have occurred in all parts of Illinois. Business losses resulting from winter storms are eight times the direct losses to property and vegetation, and the greatest direct loss was $12.4 million in a 1924 storm. Five synoptic weather types cause severe winter storms, and the Colorado low with a southerly track produced 45 percent of all storms.

Reference: Changnon, Stanley A., Jr. Climatology of Severe Winter Storms in Illinois. Illinois State Water Survey, Urbana, Bulletin 53, 1969.

Indexing Terms: applied climatology, blizzards, design storms, glaze, heavy snow, hydrologic budget, ice storms, Illinois, lake effect, severe storms, sleet, snow, storm damages, storm models, synoptic climatology, wind with glaze.

STATE WATER SURVEY DIVISION
WILLIAM C. ACKERMANN, Chief

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by Stanley A. Changnon, Jr.

ABSTRACT

Severe winter storms, which usually produce snowfall in excess of 6 inches and often are accompanied by damaging glaze, normally occur five times a year in Illinois, and they produce more damage than any other form of severe weather including hail, tornadoes, or lightning. In the 1900-1960 study period these storms were most frequent in January, but the dates when storms were most frequent were 23, 24, and 25 December, with storms occurring on these dates in 15 percent of the years.

The centers of the storms occurred most frequently in northwestern Illinois, and the average storm produced at least 1 inch of snow over 32,200 square miles and more than 6 inches over 7500 square miles. The storms generally moved from the southwest, and the storm centers were elongated with an axial ratio of 3:l and WSW-ENE orientations.

Damaging glaze was produced in 92 storms in the 61-year period. Glaze-producing storms occurred most frequently in December, and the centers of glazing were usually in central Illinois. Glazing with a thickness of 2 inches has occurred in most areas of Illinois. Point snowfalls of 12 inches or more have occurred in all state areas, and a maximum of 37 inches at a point occurred in one 1900 storm. Many other results pertaining to all types of design problems relating to severe winter storms are also presented.

The study of storm damages in the 1910-1960 period revealed that the most damaging storm occurred on 17-19 December 1924 and produced $12,400,000 in property damages. Unmeasurable business losses resulting from severe storms are estimated to be eight times the direct losses to property and vegetation.

Five weather types lead to the production of the severe winter storms in Illinois. The Colorado low with a southerly track produced 45 percent of the winter storms, and generally produced the most widespread heavy snows, more damaging glaze conditions, and more overall damage than did the other weather types.

INTRODUCTION

A detailed climatological study of all severe winter storms occurring in Illinois during the 1900-1960 period has been pursued to obtain extensive information concerning these frequently quite damaging snow and ice storms. This study provides information that enlarges our knowledge of the basic climatological aspects of winter storms, statistics concerning the amount and types of damage they produce, descriptions of the meteorological conditions producing these storms, and data helpful in the design and planning for these events.

Severe winter storms in Illinois produce more total damage than any other form of short-term severe weather including hail, lightning, and tornadoes. Specific, complete dollar-loss figures are impossible to obtain for most severe winter storms, and this makes an exact evaluation of their damage-capability difficult. Furthermore, certain forms of economic loss associated with winter storms, such as reduced commercial operations resulting from absenteeism caused by transportation stoppages, is extremely difficult to assess. Deaths and injuries to humans have resulted from many Illinois winter storms. A large percentage of the property damages are experienced by commercial carriers, communication media, utility companies, and by various vegetation (figure 1).

It appears reasonable to conclude that, on the average, severe winter storms each year produce more than $2 million in property damage, 4 deaths, and at least 40 injuries, plus an untold amount of loss to commercial operations and extensive personal hardships. In comparison, the annual average losses for tornadoes are $1.2 million and 5 deaths[1]; those from lightning are $0.1 million and 6 deaths[2]; and average hail losses amount to $2.2 million and no deaths.[3] Severe winter storms do contribute sizable amounts of moisture for storage in surface reservoirs, and the snow cover protects winter crops and helps prevent erosion.

Figure 1. Results of severe winter snowstorms in Illinois (Chicago Tribune photo)

This report is organized into three major parts, preceded by a section describing the data employed to define the 304 storms in the 61-year period and the types of analyses used. Part 1 of the report is primarily a climatography of the 304 winter storms. In this, their temporal variations, including hourly, daily, monthly, and annual frequencies, are described along with their geographical patterns and areal frequencies across Illinois. One section is devoted to statistics on storm damages including the worst storms, types of damages, and weather conditions related to the most damaging storms. Another section includes a detailed study of the meteorological conditions that produced these storms, and a final portion concerns snow and glaze patterns exhibited by various unusual severe winter storms.

Part 2 presents a comparable study of the 92 storms that were classified as glaze storms. Most of these produced widespread damaging glaze, either with or without large snowfalls. A separate climatography of glaze storms was made because many produced quite extensive damages. The climatological statistics presented for these storms include various temporal and areal frequencies, damage data, and information on the meteorological conditions that produced them.

Severe storm information useful in designing structures and in operational planning is the subject of Part 3 of the report. Certain data presented in Parts 1 and 2 are summarized in this final section. Averages and extremes of storm frequency, snowfall depth, and ice thickness are presented for points throughout Illinois. Models of severe winter storms are shown, and regional statistics are offered concerning the probabilities of a sequential series of storms, persistence of post-storm damaging conditions, and areal and temporal likelihoods of storms.

Data from a detailed analysis of a very severe winter storm in January 1967 were incorporated in various sections of the report to provide certain comprehensive information that was not available for the storms in the 1900-1960 period.

Acknowledgments

This report was prepared under the direct supervision of Glenn E. Stout, Head of the Atmospheric Sciences Section, and under the general supervision of William C.

Ackermann, Chief of the Illinois State Water Survey. Special credit is due Harold Q. Danford who performed many of the synoptic weather analyses for the 304 winter storms. During the five years that this research has been in progress, several persons were involved in the difficult and sizable task of data reduction and map plotting. Among those who greatly assisted in these activities were I-min Chiang, David Pingry, Ruth Braham, and Edna Anderson. Helpful suggestions on the contents of this report have come from Floyd A. Huff, Hydrometeorologist on the Survey staff, and from David M. Hershfield of the Agricultural Research Service. Since this report could not have been compiled without availability of the original records of the U. S. Weather Bureau stations in Illinois, the assistance of William L. Denmark, State Climatologist for Illinois, in making these data readily accessible is gratefully acknowledged. The entry of the storm data in punch cards and the ensuing machine analysis were performed under the supervision of Marvin C. Clevenger, Machine Supervisor on the Survey staff. Mrs. J. Loreena Ivens, Technical Editor, edited the report. John W. Brother, Jr., Chief Draftsman, and William Motherway, Jr., Draftsman, prepared the illustrations. Special thanks are due the many businesses and commercial organizations and their personnel who supplied detailed damage data for the January 1967 storm.

DATA AND ANALYSES

Data

A major source of data for this study was the climatological data publications of the U. S. Weather Bureau issued monthly in the 1900-1960 period.[4] In many of these issues weather summary texts appear, and these contained descriptions of many damaging winter storms, including the amount and types of damage. Old newspapers also were studied to obtain additional data on the amount of damages. Data on the occurrence of 6-inch or greater snowfalls in 48 hours and on daily glaze occurrences were obtained from an examination of the published monthly issues of *Climatological Data,* from a computer analysis of the daily snowfall data entered on IBM cards for 62 Illinois stations with long records,[5] and finally from a search of the original, unpublished weather records of all other U. S. Weather Bureau stations in Illinois.

Additional weather data relating to each storm came from these unpublished records of the Weather Bureau substations. In addition to the amounts of snowfall and the glaze occurrences, data obtained included the beginning and ending times of the snow or glaze, local damages, persistence of damaging snow and glaze conditions after the storm, and the occurrence of other weather phenomena such as sleet and high winds. Considerable data on extreme glaze conditions were found in research reports dealing with glaze.[6,7]

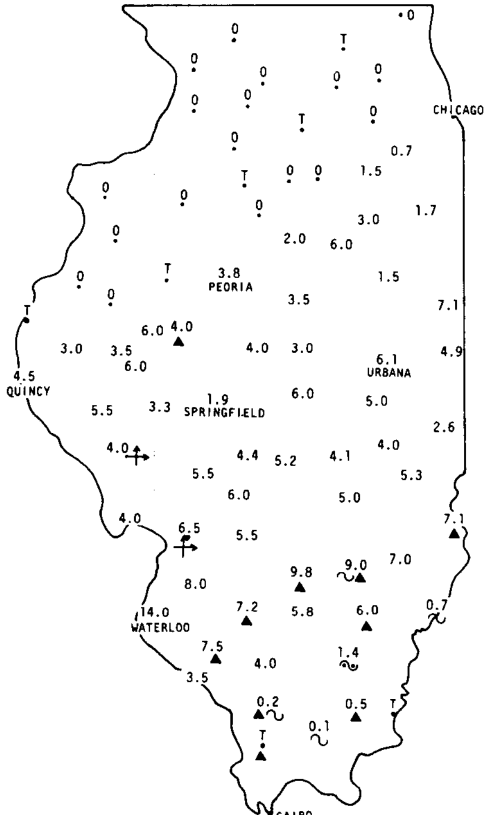
Storm Identification

Before the analyses of severe winter storms could be initiated, quantitative criteria to identify their occurrence were needed. The most desirable identification would have been that based on the amount of damages produced by a winter storm. Unfortunately, such data were not available in the weather records for many obviously damaging storms, so definitions based on available, quantitative weather data (such as the amount of snow or extent of glaze) were devised.

The snowfall amounts and areal frequencies of glaze and sleet reports associated with several storms that had known large losses were identified and analyzed. This analysis revealed that in most instances damaging (severe) winter storms were those that produced 6 inches or more snowfall in 48 hours or less at some point in Illinois and/or those in which glaze covered at least 10 percent of the state. This agrees with the U. S. Weather Bureau's heavy snow warning which is issued for an area when a fall of 6 inches or more is expected in a 24-hour period. Sleet often accompanied glaze and snow storms but was not a separable damaging event.

The historical storm analyses also showed that all damaging snow or glaze storms began and ended within Illinois during a 60-hour period or less, and were the result of a single, definable set of meteorological conditions. In cases when heavy snow and glaze continued intermittently over 4-, 5-, or 6-day periods, there was actually a series of two or three storms, each produced by a different set of meteorological conditions.

The severe winter storms in Illinois were identified and selected by one or more of these established criteria: 1) a snowstorm that produced 6 inches or more snowfall at a point in 48 hours or less; 2) a snowstorm that produced conditions leading to property damages, deaths, or injuries regardless of the amount of snowfall; 3) a glaze storm in which 10 percent of the cooperative U. S. Weather Bureau substations in Illinois reported glaze; and 4) a glaze storm in which property damages, deaths, or injuries occurred. The second definition had to be included because a few storms in which the maximum point snowfall in Illinois was only 4 or 5 inches produced damages because the snows were associated with high winds resulting in drifting sufficient to cause traffic stoppages and auto accidents.



a. Weather data available for 8-9 January 1920

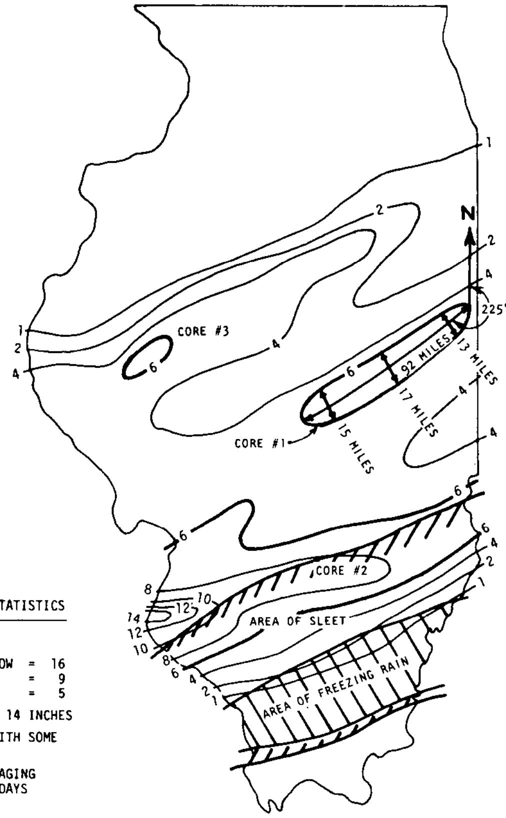
SUMMARY OF STORM STATISTICS

NUMBER OF STATIONS
≥6 INCHES OF SNOW = 16
SLEET = 9
FREEZING RAIN = 5

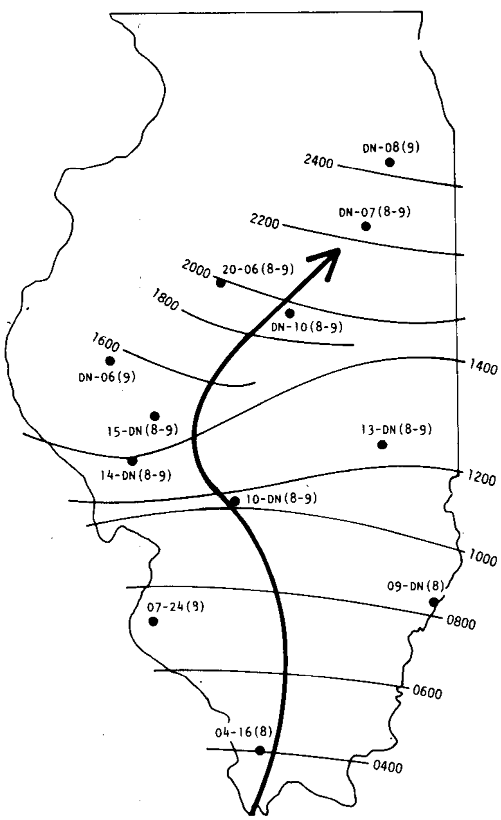
MAXIMUM SNOWFALL = 14 INCHES

MODERATE DAMAGES WITH SOME DUE TO GLAZE

PERSISTENCE OF DAMAGING CONDITIONS = 2 DAYS



b. Patterns of snowfall, glaze, and sleet



c. Times of beginning and ending of storm and forward advance

EXPLANATION

a.

0.5 = INCHES OF SNOW
STATION LOCATION

= FREEZING RAIN

= DAMAGING FREEZING RAIN

= BLOWING SNOW (BLIZZARD)

▲ = SLEET

b.

6 = INCHES OF SNOW

= SLEET AREA

= GLAZE AREA

c.

2200 = ISOCHRONES (CST) OF STORM START

04 = 0400 CST

(8) = DATE

DN = DURING THE NIGHT EXACT TIME UNKNOWN

Figure 2. Data and analysis of severe winter storm on 8-9 January 1920

Analyses

The available data for each storm were plotted on an Illinois base map, as illustrated in figure 2a. A text also was prepared for each storm, describing all other available information, including the amount and type of damage. Snow isolines and areas of glaze were circumscribed (figure 2b).

Several desired storm statistics then were derived from these maps and texts. Storm beginning times at all points were used to calculate the storm motion across the state (figure 2c). The storm-start isochrones for the storm on 8-9 January 1920 reveal that it moved from the south. The time of each storm start within Illinois also was determined from the storm maps.

The areas of 6-inch or greater snowfalls were labeled as storm 'cores' as a means of objectively identifying areas of storm maximization. Several measurements of these cores were made, including their length, which was defined as the greatest straight-line distance within the area; their orientation, which was that of the length measurement; and their width, which was an average determined from three width measurements taken at right angles to the length at different locations. In core number 1 (figure 2b) the length was 92 miles, its orientation was 225 degrees, and the average width based on the three indicated width measurements was 15 miles. In certain very extensive storms, or those near the state boundaries, the length and width of cores could not be determined because the 6-inch isolines extended beyond Illinois (core number 2 in figure 2b). This limitation affects the mean calculated for the lengths and widths of cores, making them slight underestimates. As shown in figure 2b, many storms had two or more cores, and measurements were made for each.

A storm duration was the average at a point as determined from the durations at the stations in the center of the storm (in and around the heaviest snowfall amounts, or if little snow, at the center of the glaze area). In the example (figure 2c), the beginning and ending times were available at only three stations, and the storm duration was 13 hours.

The persistence of deep snow cover and/or damaging glaze at each station in the center (core or cores) of the storm was listed. These values were used to calculate an average persistence value for each storm, which for the 8-9 January 1920 storm was 2 days. Also listed for each storm was the number of stations reporting glaze, sleet, and 6-inch snowfalls.

To ascertain whether a given storm qualified as a glaze storm, regardless of the amount of snow, there had to be recorded damages from glaze or the number of glaze reports had to equal or exceed 10 percent of the number of reporting stations that year in Illinois. The number of reporting stations was 70 in the 1900-1920 period, 90 in the 1921-1940 period, 130 in the 1941-1950 period, and 170 in the 1951-1960 period. Thus, a 1910 storm qualified as a glaze storm if it had 7 stations with glaze, but a storm in 1955 had to have 17 stations with glaze to qualify as a glaze storm, unless a record of damages due to glaze was found for the storm. The illustrated storm (figure 2c) did not have sufficient reports of glaze to qualify, but there was reported damage from glaze, thus qualifying it as a glaze storm as well as a snow storm.

The damage data available for each storm also were summarized. The status of glaze damages was classified as an occurrence, as a nonoccurrence, or as unknown. The total amount of storm damage (resulting from snow and glaze) was classed into one of four categories. One class was labeled 'no damage-unknown damage' and consisted of storms with less than $1000 or those for which no damage data could be found. The 'minor' damage class was assigned to storms producing $1000 to $10,000 in damages; the 'moderate' class was for those producing $10,000 to $200,000; and the 'extreme' class included those with damages greater than $200,000 and/or those producing one or more deaths to humans. The illustrated storm (figure 2b) was classed in the moderate group. To make the damages for all storms comparable, the total dollar losses of each storm were normalized to the value of the 1960 dollar. This normalization was based on annual price indices for building materials.[8]

The study of the synoptic weather conditions related to the occurrence of each of the 304 storms was based largely on analysis of the published daily surface weather maps of the U. S. Weather Bureau. Since a uniform, comparable classification system was desired for all storms, an upper air analysis could not be incorporated because of the lack of such data for much of the 1900-1940 period. Further details about the analytical approach employed are presented in the sections describing these results. Certain synoptic weather data relating to a winter storm in 1967 were employed to reveal detailed information not available for all storms.

Part 1. Climatography of All Storms

A snow or glaze storm could be defined as a severe winter storm on the basis of four possible conditions occurring in 60 hours or less. Many storms qualified by fulfilling more than one of these four criteria, and thus many combinations of the four criteria could and did exist in certain storms. The criteria associated with the 304 storms formed 10 combinations (table 1). The greatest number in a combination is 125 storms, and these qualified because they each produced 6 inches or more snowfall, but no known snowfall damages, no glaze damages, and no widespread glaze.

The other three classes with relatively large total numbers of storms were the 6-inch snow and damage (86 storms), the class with all four conditions (32 storms), and the class with known damages, widespread glaze, and glaze damage (24 storms). The 24 storms in this last class were generally rather extensive damaging glaze storms without snow, whereas those in the snow-damage class were simply snowstorms without any glaze. The 32 storms with all four conditions were truly 'severe' storms, fulfilling all definitions of a severe winter storm.

Examination of the frequency of the different storms in each month reveals that a relatively large percentage of the December storms fell into the snow-without-known-damage class and in the glaze-damage class. Relatively few of the February and March storms were in the class defined by a 6-inch snowfall without damage or glaze.

Combining all storms in which the 6-inch snowfall criterion was met reveals that in 269 of the 304 storms at least one point in Illinois had that amount of snow. A total of 138 of these 269 storms had known damages, 40 were associated with widespread glaze conditions, and 53 also had glaze damage.

Slightly more than 50 percent of all the storms, 173, were identified as having known damages from snow and/or glaze conditions. Thirty-five of these 173 known-damage storms were associated with storms having point snowfalls of less than 6 inches. Eighty-seven of the 304 storms had glaze damages, but only 58 of the 87 with damaging glaze were associated with widespread glaze conditions. Widespread glaze conditions occurred in 63 storms, and 39 of these storms also produced point snowfalls of 6 inches or more.

Table 1. Number of Severe Winter Storms in Various Classifications Based on Combinations of Definitions

Criteria combinations	Number of storms Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
≥6 inches of snow (damages unknown and no glaze)	1	7	30	34	26	19	7	1	125
≥6 inches snow and known damages (no glaze)	0	7	13	18	20	25	3	0	86
≥6 inches snow, known damages, and widespread glaze (no glaze damage)	0	0	0	0	0	1	0	0	1
≥6 inches snow, known damages, widespread glaze, and glaze damages	0	1	6	13	8	3	1	0	32
≥6 inches snow and widespread glaze (no damage)	0	0	0	2	0	2	0	0	4
≥6 inches snow, widespread glaze, and glaze damage (amount of damage unknown)	0	0	1	1	0	0	0	0	2
≥6 inches snow, known damages, glaze damage (glaze not widespread)	0	1	5	1	6	4	2	0	19
Known damages, widespread glaze, glaze damage (snow <6 inches)	0	0	9	8	3	3	1	0	24
Known damages, glaze damage (glaze not widespread, snow <6 inches)	0	1	1	2	1	5	0	0	10
Known damages (no glaze and snow <6 inches)	0	1	0	0	0	0	0	0	1

TEMPORAL CHARACTERISTICS

Annual Frequencies

The average number of severe winter storms in Illinois during a year is 5, but there have been as many as 12 storms in one year (1912) and as few as 1 storm in one year (1919 and 1925). Maximum and minimum frequencies of storms for periods ranging from 1 to 10 years appear in table 2. In an average 10-year period, 50 severe winter storms would occur, but the 10-year extremes show 68 occurred in the 1942-1951 period (18

Table 2. Maximum and Minimum Number of Storms for Various Year-Periods

Storm occurrences	Number of storms for various periods 1-year	2-year	3-year	5-year	10-year
Maximum (year)	12 (1912)	19 (1950-51)	25 (1943-45)	35 (1943-47)	68 (1942-51)
Minimum (year)	1 (1919, 1925)	5 (1902-03, 1907-08, 1919-20, 1937-38)	8 (1919-21)	16 (1919-23)	36 (1916-25)

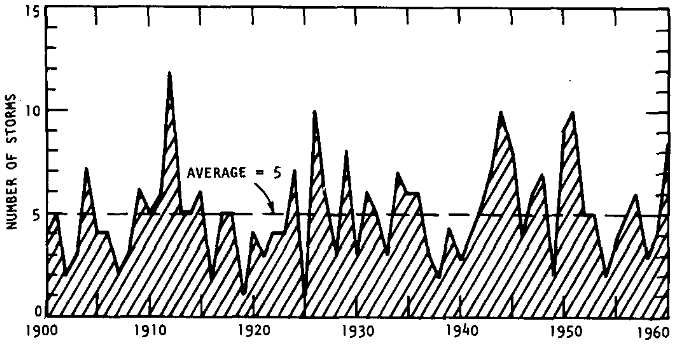


Figure 3. Annual number of severe winter storms

above average) and 36 occurred in 1916-1925 (14 below average).

The annual number of storms in 1900-1960 are plotted in figure 3. This time distribution shows that 3-year or longer low frequency periods occurred in 1905-1908, 1919-1923, and 1937-1941. Three-year or longer high frequency periods occurred in 1909-1912, 1934-1936, and 1943-1945. The annual frequency data were tested for the existence of cycles in their occurrences, but no evidence of a cyclic distribution was found.

Monthly Frequencies

The total number of storms in each month is shown in table 3. The earliest storm occurred on 28-30 October 1925, and this was the only severe winter storm to occur in October. The latest storm in spring occurred on 1-2 May 1929, and this was the only severe winter storm to occur in May. January, with 79 storms, had the greatest number, and numbers in December, February, and March were almost equal. The numbers in November and April were of comparable magnitude. The four months beginning with December have yearly averages of 1 storm, although the January value is somewhat greater than 1 and in an average 10-year period 13 winter storms occur in January.

The monthly extremes (table 3) reveal that as many as 5 storms have occurred in March (1912), and 4 storms have occurred in a single December (1915 and 1951) and in January (1918 and 1957). There have been cases with no severe winter storms in all the cold season months. Probabilities for the occurrence of 1, 2, 3, or more severe winter storms in each month are presented in table 4. There is a 70 percent chance for 1 or more severe storms to occur somewhere in Illinois during January and a 43 percent probability for 2 or more storms in any January. February and March both have probabilities of about 60 percent for 1 or more storms.

Table 3. Average and Extreme Monthly Number of Storms

Sorm ocurrences	Number per month: Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Total, 1900-1960	1	18	65	79	64	62	14	1
Average per year	*	*	1	1+	1	1	*	*
Maximum in 1 year	1	2	4	4	3	5	2	1
Minimum in 1 year	0	0	0	0	0	0	0	0

Considerably less than 1

Table 4. Probability for Severe Winter Storms

Number of severe storm ocurrences	Probability (percent): Nov	Dec	Jan	Feb	Mar	Apr	Year
1 or more	25	67	70	62	60	21	100
2 or more	5	25	43	31	30	2	96
3 or more	<1	12	15	12	7	<1	87

Daily Frequencies

The number of times that a severe storm occurred on each date in the 15 November to 19 April period was determined and then plotted (figure 4). The distribution of the occurrences is not uniform with certain periods having relatively higher frequencies than dates on either side of these periods (27-28 November, 22-26 December, 25-26 February, 2-3 March, 10-12 March, 18-20 March, and 25-26 March). The daily frequencies in January and most of February vary but do not exhibit any marked high incidence periods. Notable periods of low incidence of storms include 3-4 December, 15-17 December, 3-5 January, 23-28 January (time of the well-known January thaw), 20-24 February, 15-17 March, and 21-24 March. The high frequencies on 24, 25, and 26 December and on 2-3 March equate to probabilities of 15 percent for a severe storm occurrence on each of these dates.

Time of Occurrence

The time that each storm initiated in Illinois could be identified for 284 storms. The number of initiations in each hour was determined, and the hourly distributions appear in figure 5. The preferred 4-hour period of initiations was from 0900 to 1300 CST when 33 percent of the

Figure 4. Number of times a severe winter storm occurred on each date somewhere in Illinois

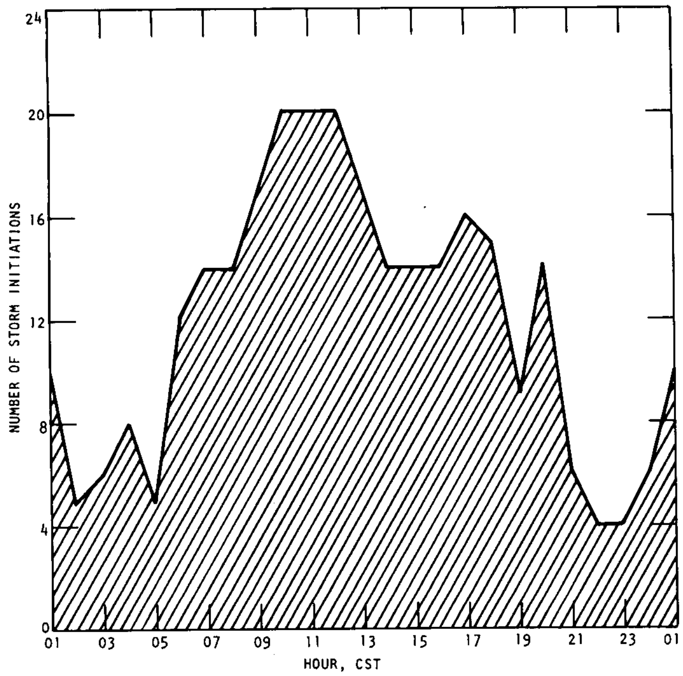


Figure 5. Time of initiations of severe winter storms in Illinois

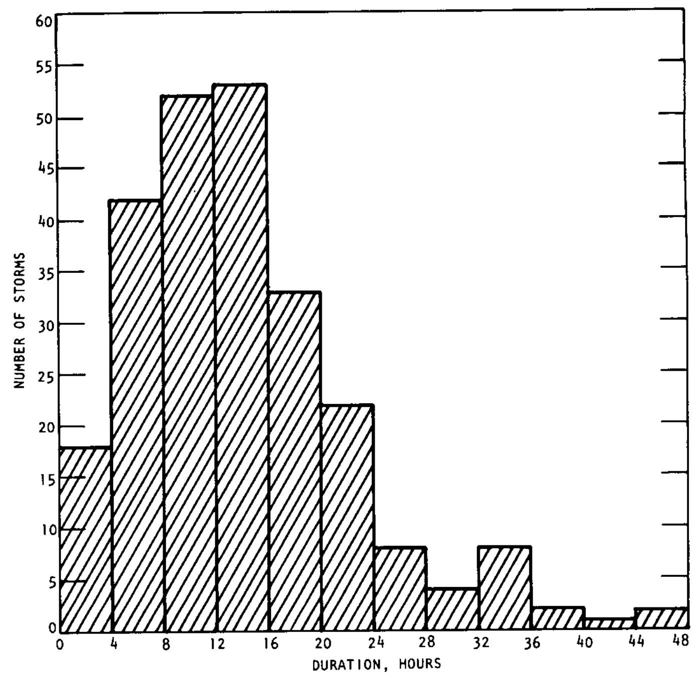


Figure 6. Frequency distribution of average point durations of severe winter storms

storms began; in general, most storms began in the daylight hours.

Examination of the hourly distributions of initiations in each month revealed no significant differences from that shown in figure 5 for all the storms. The peak shown for the hour ending at 0100 was a result of initiations at this time occurring in December, January, and February. The diurnal distribution of hours when measurable snowfall occurs in most of Illinois also shows a peak of activity in the daylight hours.[9]

Storm Point Durations

The average point duration could be determined for 245 of the 304 storms. As shown in table 5, these values ranged from a low of 2.0 to a high of 48.0 hours, with a median of 14.2 hours. The average duration of all measurable snowfalls in Illinois varies from 5.1 hours in southern Illinois to 6.3 hours in northern Illinois.[9]

More than 80 percent of the duration values in each month were less than 20 hours, but the distribution of values was quite skewed, with a few storms in the 30-hour or longer range in each month. Therefore, mean monthly durations were less meaningful than were median durations. The skewness of the duration distribution is revealed in figure 6, which is a histogram based on all 245 storms. Sixty percent of all storms had average point durations between 4 and 16 hours, whereas 10 percent had durations ranging from 24 to 48 hours.

The median monthly durations (table 5) reveal that storms in December and January were somewhat longer lived at a point than those in other months. Durations of storms in November and April were notably less than those in the other months.

Table 5. Median and Extreme Point Durations for 245 Severe Winter Storms

Storm duration	Duration *(hours)* Nov	Dec	Jan	Feb	Mar	Apr	All storms
Maximum	35.0	48.0	35.9	47.0	42.0	34.0	48.0
Minimum	3.0	2.0	2.5	3.0	2.0	4.7	2.0
Median	9.0	14.4	14.0	12.3	13.1	8.9	14.2

AREAL-GEOGRAPHICAL CHARACTERISTICS

Areal Distribution of Storm Cores

The occurrences of 6-inch snowfall cores and damaging glaze areas in each of the nine crop reporting districts in Illinois were tabulated on a monthly and total basis. The total based on the number in each district were considerably greater than the 304 storm total because 1) many storms had two or more snowfall cores (*see* table 8) as well as glaze areas, and 2) a core often extended over three or four districts and was counted as an occurrence in each district.

The monthly patterns in figure 7 exhibit latitudinal distributions. The NE district has a maximum frequency in November, December, and April. Both southern dis-

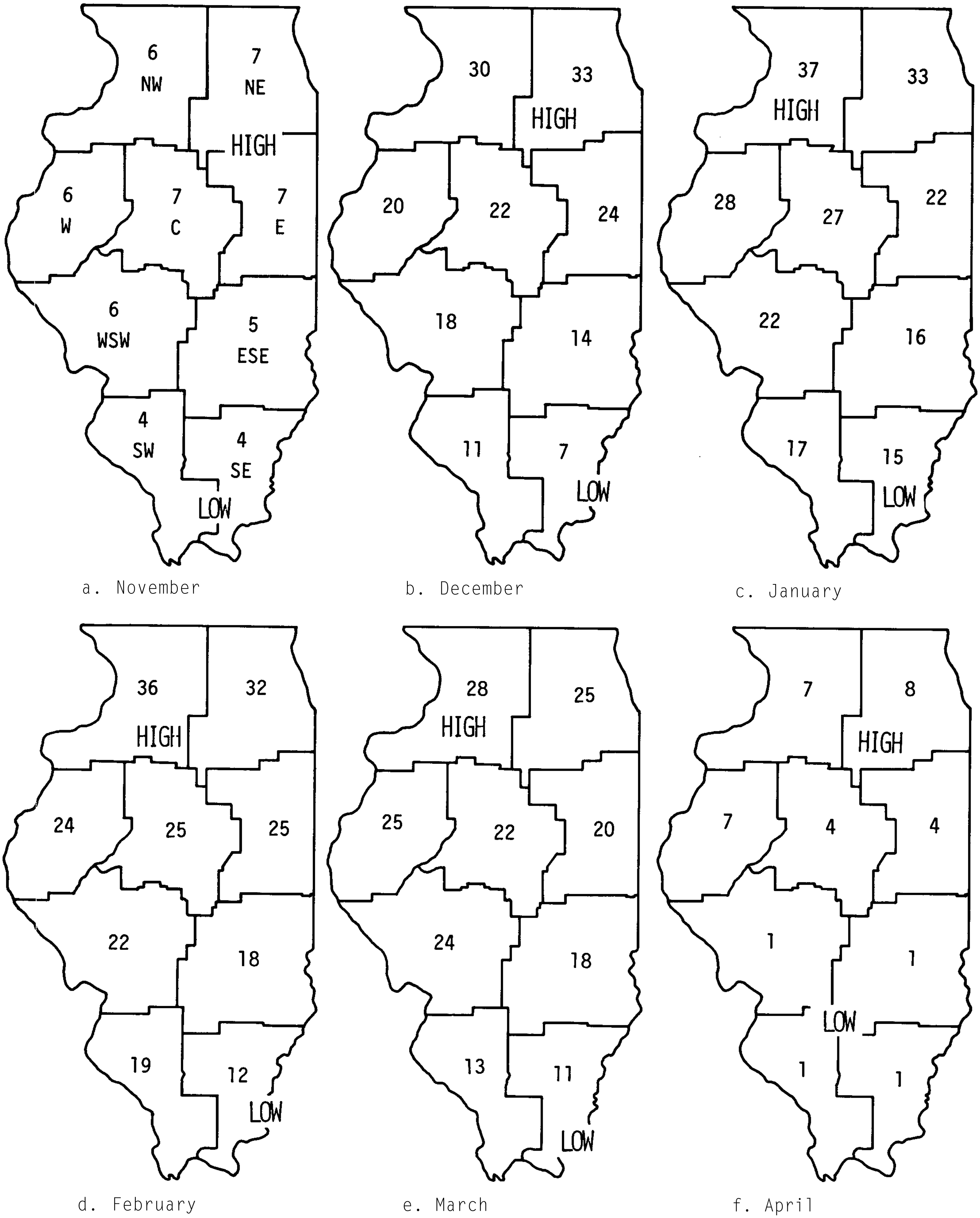


Figure 7. Monthly number of times a 6-inch snow core or glaze damage urea occurred in 1900-1960 period

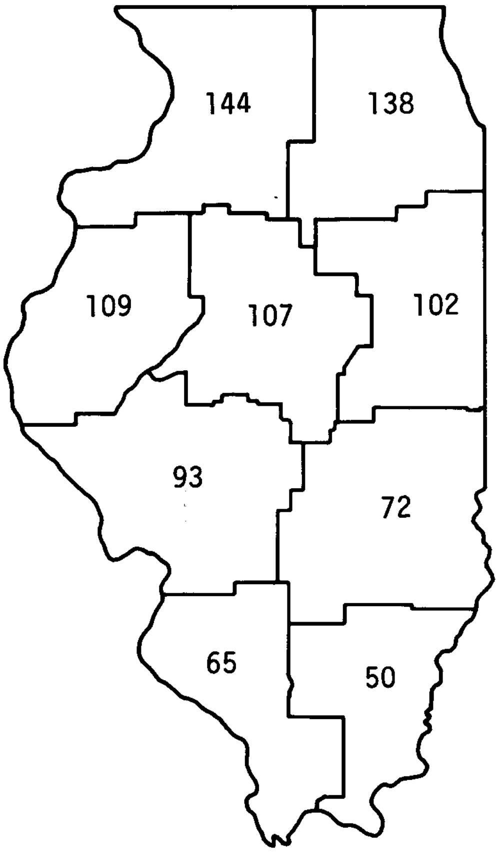


Figure 8. Number of times a 6-inch snow core or glaze damage area occurred in 1900-1960 period

tricts have low occurrences in November and April; in all other months, the SE district has the lowest number of storm core occurrences. The NW district led all districts in number of cores in January, February, and March. The March pattern reveals less latitudinal distribution than in other months with relatively high frequencies of storm cores in the W and WSW districts. Although the areal distribution is generally latitudinal in January, February, and March, there is also a tendency for a decrease from west to east.

The total number of core (snow or glaze) occurrences in each district during the 1900-1960 period is shown in figure 8. This pattern also reflects the latitudinal north-south decrease through Illinois, as well as the west-east decrease across Illinois.

The location of the maximum snowfall value in each storm producing 6 inches or more (total of 269 storms) was identified and plotted. On this map, a grid consisting of rectangles with a width of 30 seconds in longitude and a length of 30 seconds in latitude (about 935 square miles) was constructed (figure 9a), and the number of storm maximums in each rectangle was calculated. The pattern based on these grid values appears in figure 9b, and four areas where storm maximum snowfalls have frequently occurred are indicated. The major high in Illinois is oriented SW-NE in northwestern Illinois. The second high occurrence area is in northeastern Illinois (Cook and Du Page Counties) ; the third is in south-central Illinois; and the fourth is in extreme southeastern Illinois. Quite low incidence areas occur in central Illinois (Sangamon County) and in east-southeastern Illinois.

The number of times an area of 6-inch or greater snowfall occurred in each grid rectangle (figure 9a) was counted for all 269 storms with 6 inches or more snowfall. The pattern based on these values (figure 9c) reveals a general latitudinal distribution. However, the area of 40 or more occurrences extends into west-central Illinois and two separate highs appear in northern Illinois. The area of least frequency is in extreme southern Illinois, although a minor high defined by the 25-isoline appears in southeastern Illinois.

Motion of Storms

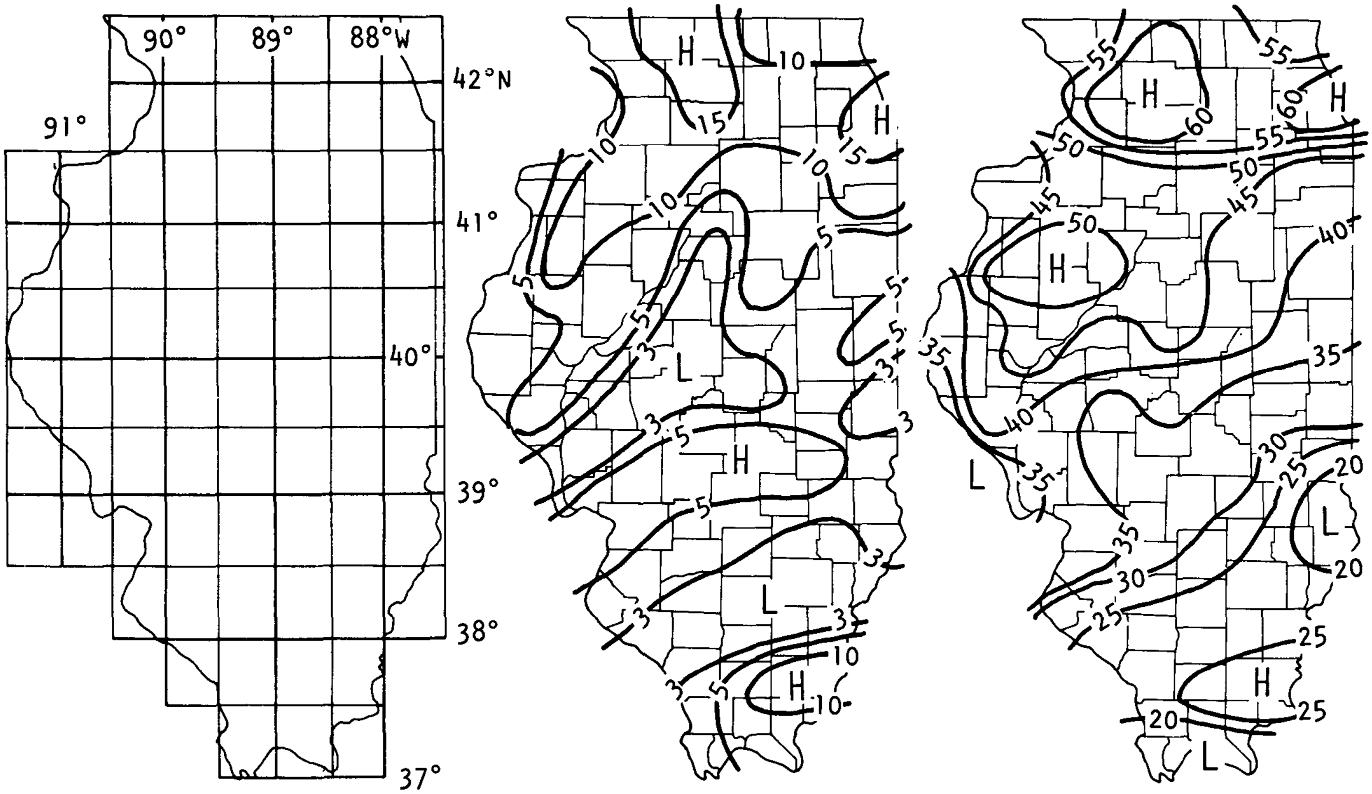
The motion of the storms across Illinois could be ascertained for 283 of the 304 storms. These motions were labeled as one of 360 possible degrees of the compass and were sorted and counted for 10-degree intervals (figure 10). A large number moved from the SW and WSW, with 47 percent moving from azimuths in the 216-255 degree sector. Minor maximums appear for storms with southeasterly motions (136-165 degrees) and for those with northwesterly motion (306-335 degrees). The three motion maximums shown for all storms (SW, SSE, and NW) also appear in motions found in all months except November, which has only a maximum of motions from the southwest. The one 10-degree sector from which storms moved most frequently in all months is 236-245 degrees.

Areal Extent of Storms

The areal extent of snowfall of 1 inch or more was determined for the 269 storms with point amounts of 6 inches or more. Average values for different snowfall increments and each month are presented in table 6. The totals shown for each month reveal that, on the average, the April snowstorms are about 30 percent smaller than those in the other five months. The average December

Table 6. Average Areal Extent of Snowfall in 269 Storms with 6 Inches or More Snow

Snowfall (*inches*)	Average number of square miles						
	Nov	Dec	Jan	Feb	Mar	Apr	All storms
1-2	5,740	6,260	7,540	6,200	6,100	6,240	6,510
2-4	9,915	11,920	10,820	10,660	10,820	6,785	10,380
4-6	7,100	8,720	6,970	7,750	7,700	4,280	7,530
6-8	3,530	4,490	4,005	4,490	4,170	2,940	4,160
8-10	2,030	1,990	2,190	1,975	2,295	1,370	2,070
10-12	710	565	1,170	925	990	945	915
>12	355	215	700	1,205	545	140	640
Total	29,380	34,160	33,395	33,205	32,620	22,700	32,205



a. Grid overlay based on 30-second by 30-second divisions of latitude and longitude

b. Distribution of maximum storm snowfall values in 269 snowstorms with 6 inches or more

c. Distribution of 6-inch or greater snowfall areas

Figure 9. Distribution of maximum snowfall, 1900-1960, based on number per grid square

snowstorm has the largest monthly value, but it is not significantly different from those in January, February, and March. However, the average areal extents of heavy snow, 6 inches or more, in January, February, and March storms are almost 1000 square miles greater than that in December.

The total value based on all storms reveals that, in the average severe snowstorm, 32,205 square miles are covered by 1 inch or more snow, which is 57 percent of Illinois. Furthermore, 7785 square miles experience 6 inches or more snowfall and 1555 square miles have 10 inches or more. In December, January, February, and March there has been at least one snowstorm that covered the state (56,400 square miles) with 1 or more inches of snow. The most extensive snowstorm in November produced 1 inch or more snow over 50,900 square miles, and the most extensive April storm spread over 54,700 square miles.

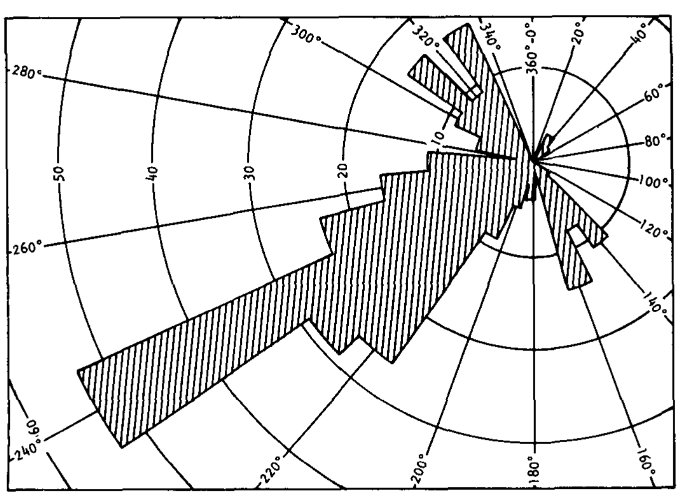


Figure 10. Direction of storm movement across Illinois sorted by number per 10-degree interval

The areal extent of glaze areas was more difficult to assess than that for snowfall because of the lack of dense point observations needed to define this either yes-or-no event. To estimate the areal extent of glaze, the number of Weather Bureau stations reporting glaze was counted for each storm. Because of the generally uniform distribution of these stations, each station was considered to represent a certain percent of the state. Since the number of stations capable of reporting glaze increased during the 1900-1960 period, the percent of state area assigned to a station was varied according to the number of stations. A station glaze report in the 1900-1920 period represented 2 percent of the state; 1 station in the 1921-1940 period represented 1 percent; 1 in the 1941-1950 period was 0.8 percent; and a report in the 1951-1960 period represented 0.5 percent of Illinois. Thus, the extent of glaze in a storm in 1912 with 5 stations reporting glaze was estimated as 10 percent of Illinois, whereas the extent in a 1955 storm with 5 stations reporting was 2.5 percent.

These values were sorted into percentage intervals by month, and the monthly and total distributions are shown in table 7. No glaze occurred in nearly half (141) of the 304 winter storms, and in 83 other storms the glaze area covered less than 6 percent (3300 square miles) of the state. In a few storms, the glaze area was quite extensive, reaching a maximum estimated state coverage of 46 percent for a single storm during 13-14 December 1937 (*see* figure 26).

Table 7. Percent of Illinois Covered by Glaze in 304 Severe Winter Storms

Percent of Illinois	Number of storms: Oct-Nov	Dec	Jan	Feb	Mar	Apr-May	Total
0	14	28	31	32	28	8	141
1–2	3	11	18	14	13	4	63
3–5	0	5	4	4	6	1	20
6–9	1	5	2	3	5	0	16
10–15	1	7	10	6	6	1	31
16–20	0	1	4	2	2	0	9
21–25	0	1	1	2	1	1	6
26–30	0	2	2	0	1	0	5
31–40	0	3	5	1	0	0	9
41–50	0	2	2	0	0	0	4
Maximum single-storm percentage	11	46	43	32	28	25	

Characteristics of Snowfall Cores

The snowfall cores, defined as areas with 6 inches or more snowfall, were analyzed for the number per storm and their size, shape, and orientation. Many storms had two or three cores, and in some storms the dimensions of some large cores could not be measured accurately, since the core boundaries extended beyond Illinois.

The number of storms with varying numbers of snowfall cores is shown in table 8. Ninety-three of the 269 storms with cores had two or three cores, but 176 storms, 65 percent of the total, had only one core. The number of multicore storms in each month represented a percentage of the total monthly storms with cores that was relatively the same in all months. For instance, the number of storms with two or three cores was 29 percent of October-November storms with cores, 30 percent of December storms, 36 percent of January storms, 33 percent of February storms, 44 percent of March storms, and 21 percent of April-May storms. Only March with relatively more multicore storms and April-May with relatively few, showed percentages somewhat different from those in the other months.

Table 8. Number of 6-Inch or Greater Snow Cores per Storm

Month	Number of storms with various numbers of cores: No core	1 core	2 cores	3 cores	Total cores	Total storms with cores
Oct-Nov	2	12	4	1	23	17
Dec	10	39	10	6	77	55
Jan	10	44	20	5	99	69
Feb	4	40	14	6	86	60
Mar	8	30	17	7	85	54
Apr-May	1	11	3	0	17	14
Total	35	176	68	25	387	269

The average widths of 65 of the 387 cores could not be determined because either very little of these cores was in Illinois or one side was beyond the Illinois boundary. Although both ends of some cores were not in the state, width values were calculated for these if the portion of the core in Illinois was at least 60 miles long. Hence, more measurements could be made for core widths than for lengths; the lengths of 274 of the 387 cores could be measured.

The number of width and length values in various class intervals of miles appears in figure 11. Nearly 38 percent of the 274 cores had lengths in the range from 1 to 50 miles, and 67 percent had lengths of less than 104 miles. The median length value was 68 miles, the longest was 325 miles, and the shortest was 10 miles. It should be realized that the median length value represents that for cores defined entirely in Illinois and many bigger cores extending across Illinois were not measured, making this median an underestimate for big cores.

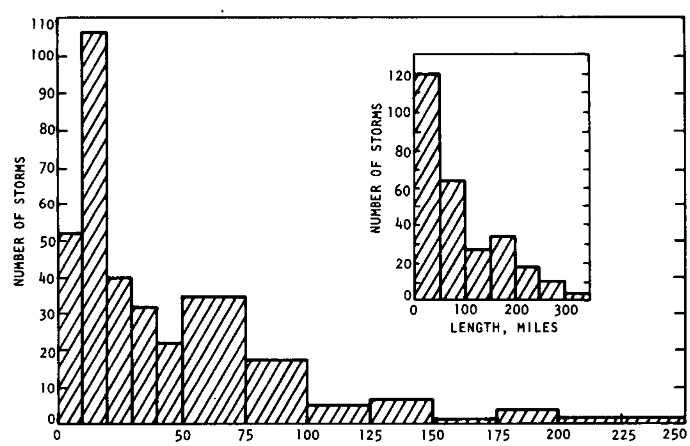


Figure 11. Distributions of lengths and widths of storm cores

The mode of the width values was the 11- to 20-mile class (figure 11). The greatest width value measured was 233 miles, the smallest was 5 miles, and the median value was 22 miles.

The frequency distributions of widths and lengths in each month did not differ greatly from the total distributions shown in figure 11. However, the cores in November, March, and April storms generally were narrower than those in the other months.

The orientation of the core (major axis) was also determined for all 387 cores in the 269 storms. These were sorted into 10-degree intervals ranging from 176-185 degrees (oriented N-S) through 346-355 (oriented NNW-SSE). The number in each 10-degree interval was used to construct the frequency diagram in figure 12. This shows that the preferred orientation of the snowfall cores was 246-255 degrees (WSW) where 72 cores occurred (19 percent). Most of the cores, 63 percent, were oriented in the 40-degree sector from 226 through 265 degrees. Similar distributions were found for the orientations of cores in all months.

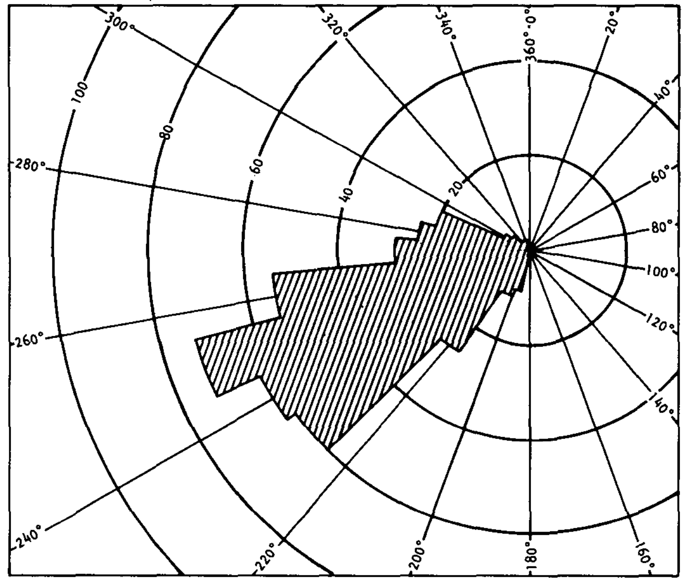


Figure 12. Frequency of orientations of storm cores

DAMAGE INFORMATION

A search of the storm damage records compiled for this study revealed that the period of most complete records was 1946-1955. In this 10-year period physical damages from 16 storms in Illinois totaled $17 million with 30 known dead and at least 350 persons injured. However, these 16 storms represented only about one-third of the 54 severe winter storms that occurred in the 1946-1955 period, and no reasonably accurate loss data were available for the other 38 storms.

Types of Damage

Severe winter glaze storms produce damages to communication and utility companies (largely through wire and pole losses, figure 13); to vegetation (breakage of branches and limbs); to building structures (broken antennas and roof damage from ice loading and falling tree limbs); and to vehicles (slick road surfaces resulting in accidents). Severe winter snowstorms also produce damages to vehicles (slick surfaces and poor visibility both producing accidents) and to buildings (roof damages from weight of excessive snow).

As examples, a glaze storm on 27 November 1955 produced 1000 traffic accidents in Chicago, and in a storm in northern Illinois on 13 February 1950, 64,000 houses lost electricity and many had broken TV antennas and were damaged from falling tree branches and excessive ice plus snow loading on their roofs. Flooding has also been a damaging by-product of a few winter storms when either heavy snowfalls melted rapidly or when heavy rain fell on heavily glazed surfaces, resulting in rapid runoff. Although the winter storms studied are those that occurred within 60 hours or less, many achieve added losses, as compared with warm season forms of severe weather, because the damaging snow or ice conditions persist at a point over much longer periods of time than do all other forms of severe weather.

Both types of conditions can result in injuries and losses of life in automobile accidents, falls on slick surfaces, freezing to death while isolated or trapped by blizzard conditions, overexertion from snow removal, and electrocution from fallen power lines. The Weather Bureau estimates that 85 percent of ice (glaze) storm deaths are traffic-related.

Either glaze or snow conditions often cause stoppages or serious delays in all transportation modes. Slick roads (glaze or snow), reduced visibility (blowing snow), and blocked roads and railroads (drifting heavy snow) all affect personal travel, business activities, and deliveries of goods and products via automobiles, trucks, railroads, and commercial air carriers. A 1951 study of traffic reduction on a main highway due to ice and snow conditions revealed that 40-percent reductions occurred on Route 66 near St. Louis.7 Business losses resulting from such delays may be partially recovered, but are hard to account for. Therefore, such 'indirect loss' figures were just not available. Such information was collected for a recent storm in January 1967, and a description of this storm is presented to illustrate the direct as well as the indirect losses.

Figure 13. Examples of heavy glaze and damages to power lines, 26-27 January 1967 (courtesy of Central Illinois cooperative)

Storm of 26-27 January 1967

The most comprehensive records of direct damages, deaths, and indirect losses ever assembled for a winter storm were collected for this storm. This storm began in Illinois at 0000 CST on 26 January and ended 26 hours later. Snowfall in northeastern Illinois exceeded 23 inches (a new record for Chicago and environs), and the associated glaze storm in central and eastern Illinois (figure 13) was a record (radial thickness of ice on wires was 1.7 inches in places). Snowfall exceeded 6 inches over the northern half of the state (26,650 square miles), and high winds produced blizzard conditions and excessive drifting. In many respects this is a design winter storm for the northern half of Illinois in that it combined excessive snow and glaze.

The losses resulting from various physical property damages were sorted by location (table 9), and these totaled nearly $22 million. However, estimates of the indirect losses to business amounted to $174 million, eight times the amount from direct losses. These data furnish an unusual perspective of catastrophic loss with $195 million in losses, 56 dead, and untold injured. Since much of the damage occurred in Chicago, some of the results of the storm in Chicago were summarized to illustrate certain conditions attendant to many very severe winter storms.

Table 9. Damages and Dollar Losses Resulting from 26-27 January 1967 Storm in Illinois

Direct losses from various physical damages

Location	Amount *(dollars)*
Chicago	3,500,000
Other downstate urban areas	5,661,000
Rural power utilities	11,029,139
Central Illinois communication companies	1,623,000
State total	21,813,139

Indirect losses to business

Location	Amount *(dollars)*
Chicago	150,000,000
Downstate	24,000,000
State total	174,000,000

Deaths

Location	Number
Chicago	31
Downstate	25
State total	56

The Chicago Transit Authority conservatively estimated their damages to be $1 million, and other commercial and private structures received physical damages estimated at $2.5 million. Losses to Chicago businesses exceeded the $150 million mark. The winds during the storm averaged 25 mph with gusts to 70 mph causing 10-foot high drifts from the 23-inch snowfall and also limiting visibility to zero. A serious problem after the storm was to find places to deposit the snow removed from streets and sidewalks. Considerable snow was loaded into empty freight trains and taken from the city to be dumped in rural areas.

Many Chicago deaths were attributed to heart attacks which occurred to persons removing the heavy snow from passageways or attempting to dig out their stranded automobiles. One small girl was shot and killed when police attempted to stop a band of looters. All told, 31 deaths directly attributable to the storm occurred in the city. Four were injured when two elevated trains collided during the storm, but an estimate of total injuries was not readily available.

For the first time in history, all the Chicago schools were closed. Though some homes were without heat, most in the city had lights and telephones. In fact, while all transportation was halted, 12 babies were delivered using telephoned instructions. About 20,000 stranded cars blocked expressways; no taxis could operate; over 3300 buses were unable to move; and even the slowly moving subways were 40 percent incapacitated. Only rescue helicopters could use the three closed municipal airports. The closing of almost all stores and factories was accompanied by minimal mail delivery, and newspaper delivery existed only in the Loop. Looting of stranded cars and closed shops reached new heights, with one looting per minute, as estimated by police. Governor Otto Kerner delayed all Chicago monetary transactions by declaring 28 January to be a legal bank holiday.

Areal-Temporal Distributions of Damaging Storms

A total of 131 storms was classed in the category of no damage-unknown damage, and because of the uncertainty of the damage data for many storms in this group, parameters of these storms were not analyzed. The minor damage category ($1000 to $10,000) consisted of 81 storms; the moderate damage category ($10,000 to $200,000) had 33 storms; and the extreme damage category (more than $200,000) consisted of 58 storms. The parameters associated with the minor, moderate, and extreme categories were analyzed in detail.

The number of storms in each damage category that qualified solely because of glaze damages, heavy snow, or because of heavy snow and glaze combined are shown in table 10. One minor damaging storm occurred with no glaze and less than 6 inches of snow. There is a relationship between the degree of damage and relative fre-

Table 10. Number of Damaging Storms for Different Definitions

Damage category	Number of damaging storms from given conditions: Glaze only	Heavy snow only	Glaze and heavy snow	Total
Minor	18	46	17	81
Modernte	5	17	1 1	33
Extreme	11	24	23	58

quency of the storms having both heavy snow and damaging glaze. These combined storms represented 21 percent of 81 minor damage storms, 33 percent of the moderate damage class, and 40 percent of extremely damaging storms.

The monthly frequencies of damaging storms (table 11) show that many of those in the minor class occurred in February and March, whereas the largest number in the moderate class was in December, and that in the extreme class was in January. Expressing the total storms with damage as a percentage of all storms shows that 57 percent of the 304 storms were damaging, and 19 percent of all storms produced extreme damage. Sixty percent or more of the storms in November, February, and March were damaging. However, a relatively large percentage of the January and April storms were extremely damaging.

The number of storms per decade in each damage category is shown in table 12. The low total number (20) for the 1900-1910 period resulted from many unknown and probably minor damaging storms in that period. Relatively few 'badly damaging' (moderate and extreme) storms occurred in the 1931-1940 decade and many occurred in the 1900-1910 and 1911-1920 periods.

The greatest number of extremely damaging storms in one year was three, occurring in 1900, 1909, and 1912. The greatest number of badly damaging storms in one year was five in 1909, 1950, and 1951, and the greatest number in one winter season was six in the 1951-1952 winter. In the 58-day period beginning on 6 November 1951 and ending 2 January 1952, there were three extremely damaging storms (on 6-7 November, 25 December, and 1-2 January) and three moderately damaging storms (on 14 December, 17-18 December, and 20-21 December). The greatest number in one month was four in December 1951 and four in January 1918 (two extreme and two moderate).

Table 11. Frequency of Damaging Storms per Month

Damage category	Number of storms: Nov	Dec	Jan	Feb	Mar	Apr	Total
Minor	6	16	15	20	24	1	82
Moderate	3	9	7	7	5	2	33
Extreme	2	9	20	11	12	4	58
Total	11	34	42	38	41	7	173
Total with damage as percent of all storms	61	52	53	60	66	50	57
Extreme-damage storms as percent of all storms	11	14	25	17	19	29	19

Table 12. Number of Damaging Storms per Decade

Decade	Minor	Moderate	Extreme	Total
1900-1910	2	4	14	20
1911-1920	12	8	12	32
1921-1930	12	7	9	28
1931-1940	19	3	6	28
1941-1950	17	6	7	30
1951-1960	20	5	10	35

Table 13. Various Characteristics of Damaging Storms

Damage category	Median point duration (*hours*)	Preferred 3-hour period of storm initiations	6-inch snowfall cores: Median length (*miles*)	Median width (*miles*)	30°-sector with most orientations
Minor	13.1	0900-1200	65	25	236-265
Moderate	16.0	1000-1300	72	30	231-260
Extreme	18.6	0800-1100	83	40	226-255

Damage category	Median percent of Illinois with glaze in storm	Average areal extent of snowfall (*square miles*): ≥1 inch	1-6 inches	6-10 inches	>10 inches
Minor	2	32,300	23,600	7,500	1,200
Moderate	4	35,600	22,400	9,800	3,400
Extreme	9	36,400	22,900	9,300	4,200

The median point durations of the storms that produced moderate or extreme damages (table 13) were considerably greater than those for all storms (table 5) or those that produced minor damage. The time of damaging-storm initiation in Illinois showed very little difference for the different degrees of damage.

As shown in table 13, the median lengths and median widths of the 6-inch snowfall cores increased with degree of damage. The orientations of the cores in extremely damaging storms were generally SW-NE, whereas those with moderate and minor damages were generally WSW-ENE.

The areal extent of snowfall and glaze (table 13) also increased with degree of damage. Two percent of Illinois had glaze with minor damage storms, as compared with 9 percent with the extreme damage storms. The average area with 1 inch or more of snowfall was 32,300 square miles for the minor damage storms, increasing to 36,400 square miles for storms producing extreme damage. In all three damage classes, the two state sections where storm cores were most frequent were the northwest and northeast, and the two sections of lowest frequency were the southwest and southeast.

Extremely Damaging Storms

The 27 most damaging storms in the 1910-1960 period are listed in table 14. Storms in the 1900-1909 period were not included because less specific data on their damages could be obtained. However, it is likely that the 27-28 February 1900 storm was one of the worst in the 61-year period. At the time of this 1900 storm, the Weather Bureau records listed it as the worst storm in Illinois since those of 1831, which was the worst winter in Illinois since the white man settled in the area that was to become Illinois.

The known dollar losses from physical damage for each storm shown in table 14 were adjusted to the 1960 dollar value, using price indices set to a 1910-1914 base.[8] This allowed comparison of losses and the assignment of ranks. The indirect losses resulting from these storms

Table 14. Damages in 27 Worst Winter Storms, 1910-1960

Storm date	Dollars of loss, adjusted to 1960 value	Number dead	Number injured	Storm rank
20-21 Feb 1912	2,000,000	4	U	10
21 Feb 1913	600,000	U	U	22
6-7 Jan 1918	1,240,000	U	U	17
11-12 Jan 1918	4,960,000	U	U	2
16-17 Apr 1921	1,413,500	U	U	15
11-12 Mar 1923	2,016,000	0	U	9
17-19 Dec 1924	12,400,000	2	M	1
30-31 Mar 1926	3,690,000	U	M	6
18-19 Dec 1929	2,520,000	U	U	8
25-26 Mar 1930	2,580,000	U	U	7
1-2 Mar 1932	1,233,840	U	U	18
7-8 Jan 1937	1,971,000	0	M	11
6-8 Apr 1938	1,370,000	0	U	16
29-30 Jan 1939	1,518,000	3	46	14
29-30 Jan 1947	894,240	2	1	21
31 Dec 1947– 1 Jan 1948	3,930,000	0	U	4
10 Jan 1949	990,000	1	M	20
17-18 Jan 1949	495,000	0	M	26
13 Feb 1950	4,270,000	2	M	3
9-10 Apr 1950	1,830,000	4	U	12
6-7 Nov 1951	575,000	U	U	23
25 Dec 1951	575,000	U	U	24
21-22 Mar 1955	3,890,000	7	U	5
8 Dec 1956	540,000	0	M	25
20-22 Jan 1959	1,545,000	U	U	13
9-10 Feb 1960	350,000	7	21	27
19-20 Dec 1960	1,000,000	U	U	19

° *U = unknown number, M = many but exact number not available*

are not known, but the 8:1 ratio (table 9) between indirect and direct losses in the January 1967 storm suggests that indirect losses would easily exceed the known direct damages shown in table 14.

The patterns of the four most damaging storms are portrayed in figure 14. The most damaging storm created more than $12 million in property damages, killed 2, and injured many. This was a glaze-only storm, with the highest point snowfalls under 5 inches (figure 14a). The direct loss in this storm was about 50 percent of that in the 26-27 January 1967 storm, further revealing that the 1967 storm was the most damaging winter storm in Illinois in the period since 1900.

The second-ranked storm in the 1910-1960 period was the opposite of the 1924 storm, being basically a snow-only storm with no glaze in Illinois. Although point snowfalls did not exceed 13 inches (figure 14b), much of the state experienced high winds that produced blizzard conditions and excessive drifting, and the entire state had more than 1 inch of snow. The damaging conditions of this storm persisted for 20 days after the storm.

The third-ranked storm (figure 14c) was a combination snow and glaze storm, and was confined to the northern third of Illinois. The damages in the fourth-ranked storm (figure 14d) primarily came from exceptional glaze loading and damages in northeastern Illinois (see table 28).

METEOROLOGICAL CONDITIONS WITH SEVERE WINTER STORMS

Historical surface weather maps prepared by the U. S. Weather Bureau were the main source of data for selecting the meteorological conditions which produced the severe winter storms in Illinois between the months of November and April for the 61-year study period. Data published in issues of the *Monthly Weather Review* were also utilized to supplement missing weather maps.

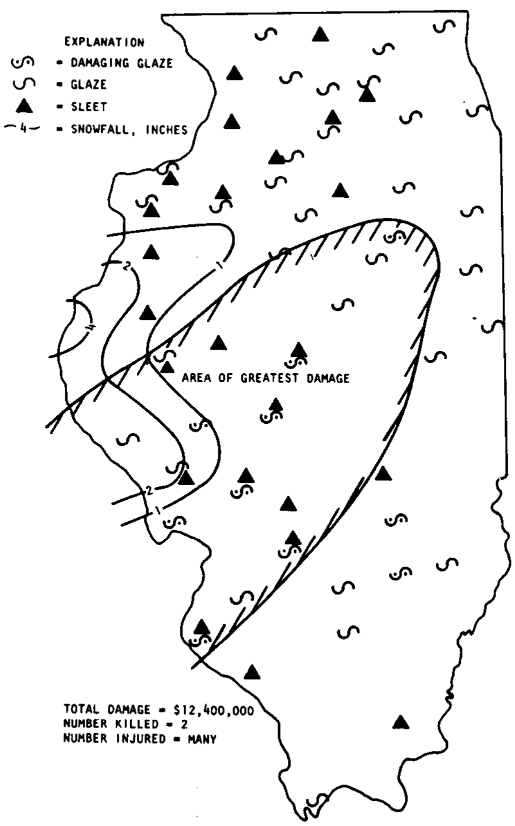
Storm Classification

Because of its physical location, Illinois comes under the influence of at least two principal storm tracks during each cold season month (November through April). During January and February, the state is subjected to three principal storm tracks.[10] Examination of weather conditions with the 304 storms indicated that with few exceptions, severe winter storms in Illinois were associated with transitory cyclones. Cyclones which led to the Illinois storms were classified according to the place of origin, to the place of major intensification or re-formation, and to their route of movement.

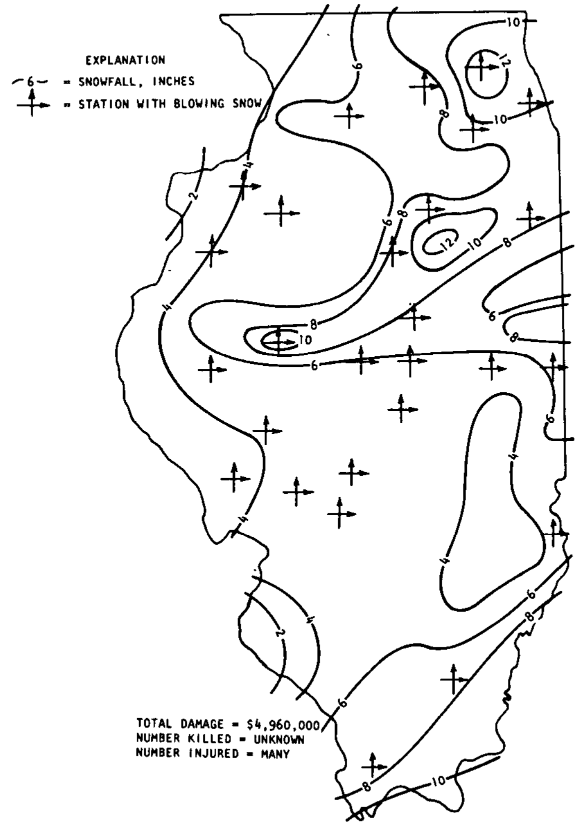
This rather broad classification was necessary because the available weather data prior to 1935 made it extremely difficult to determine whether the observed cyclone was an original development or if it was an old system that had temporarily lost its surface identity and then moved into an area favorable for re-formation. Almost all cyclogeneses in middle and high latitudes occur in connection with fronts.[11] The initial movement of a cyclone is normally ill-defined. Only after the disturbance has intensified and moved out of its immediate cyclogenic region does it attain a regular path. It tends to follow over locally warm surfaces, such as inland bodies of water. [10]

Areas of favorable cyclogenesis initially were divided into two localities, the lee of the North American Rockies and the Gulf of Mexico. Because of the great latitudinal extent of the North American Rockies, this area was separated into two regions of frequent development, Alberta and Colorado. All of these developmental regions have the necessary physical features to maintain a quasi-stationary surface front. In Alberta and Colorado, adiabatic warming of air descending the mountains sustains the lee-of-the-mountain fronts,[12, 13] and the warm water surfaces in the Gulf of Mexico during the winter maintain a frontal boundary along the Gulf Coast.[14]

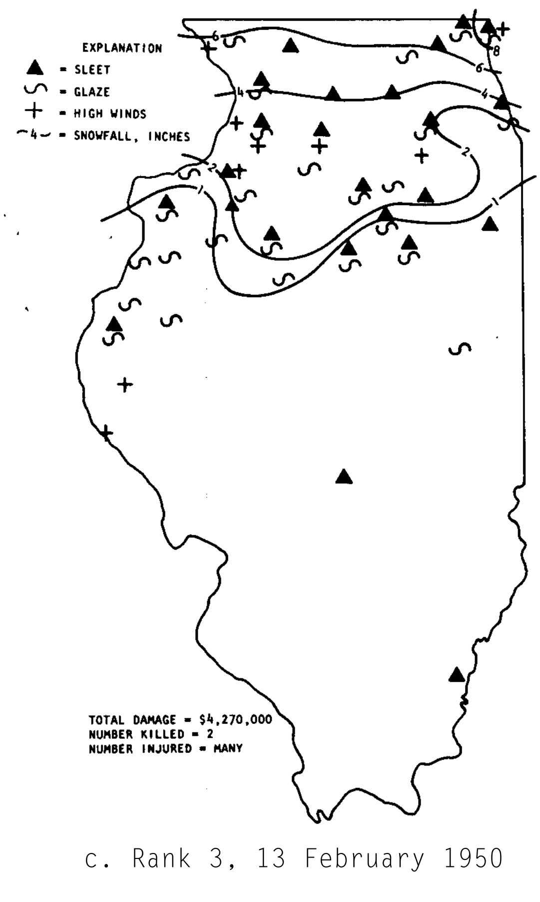
In addition, all three areas are subjected to the penetration of arctic and polar air masses. Each of the three areas lies in the path of cold core systems which move



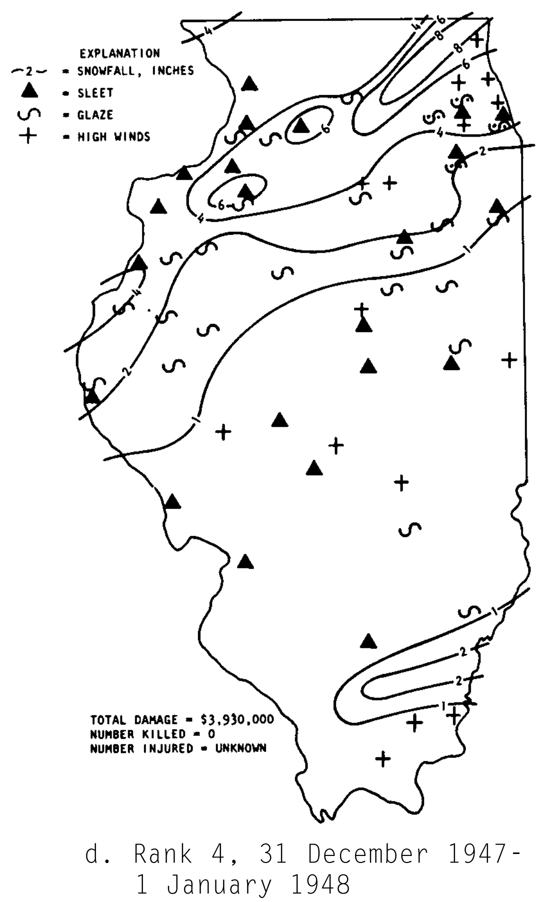
a. Rank 1, 17-19 December 1924



b. Rank 2, 11-12 January 1918



c. Rank 3, 13 February 1950



d. Rank 4, 31 December 1947-
1 January 1948

Figure 14. Patterns of snow, glaze, and other conditions associated with four most damaging storms in 1910-1960

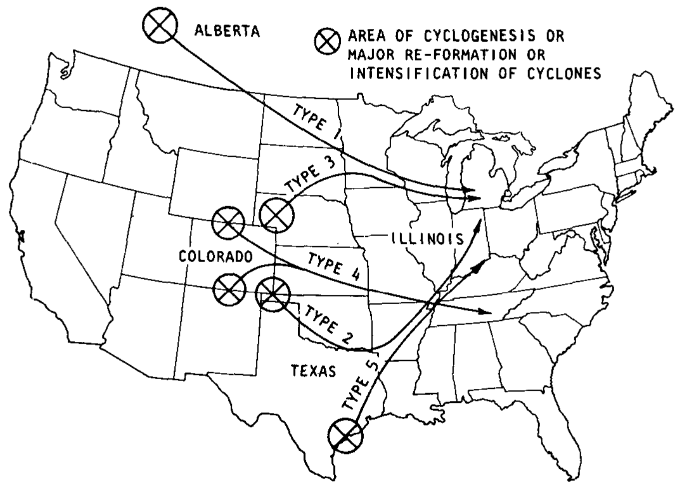


Figure 15. Schematic of weather (cyclonic) types related to severe storms in Illinois

out of the Pacific and may or may not be recognizable from surface data by the time they reach their respective cyclogenic areas. All three areas lie in the general vicinity of normal fields of convergence during the winter months.[15]

Weather Types

Alberta cyclones, labeled as the type 1 storm producer, were defined as those lee-of-the-mountain cyclonic developments which formed north of the U. S.-Canadian border and moved easterly into the Great Lakes Basin (figure 15). The border is a good dividing line, since it is an area of minimal cyclogenesis. These Alberta cyclones produced 34 of the Illinois winter storms, or 11 percent of the total.

The 182 cyclonic developments in the Colorado area that led to severe winter storms were separated into three storm-producing types according to the route traveled in their easterly migration. Type 2, the most frequent severe winter storm producer in Illinois, formed either in southeastern Colorado or in the adjacent Great Plains area. This type tends to move into the junction of the Mississippi-Ohio River Basins, and thence northeastward into the Great Lakes Basin and beyond (figure 15). The route is parallel to and to the south of the preferred winter position of the polar front which is oriented WSW-ENE across central Illinois.[29] These type 2 cyclones moved either continuously at a rapid rate or intermittently with stagnation. While stagnant, they received additional intensification in the Ohio Valley or the Great Lakes Basin. There were 137 storms, or 45 percent of the total number, with type 2 development.

Type 3 was defined as that cyclone which appeared in the northern Colorado and adjacent Great Plains area and moved northward, sometimes as far as the Canadian border. It then migrated into the Great Lakes Basin, passing north of the Ohio River system. This type produced 23 storms, or 8 percent of the total. Type 4 was defined by the cyclones that originated in either northern or southern Colorado and migrated eastward along a route south of the Ohio River system. This type related to 22 storms, or 7 percent of the total.

The Texas-West Gulf cyclone, labeled as type 5, departed from the Gulf of Mexico and took any one of several paths northward. The type 5 cyclones produced 74 storms, or 24 percent of all the severe winter storms. A few of the Alberta cyclones moved down the frontal surface in the lee of the Rocky Mountains, crossing the Colorado cyclogenic region, and on into the West Gulf area. Here they received intensification and moved northward into a position where they produced a severe winter storm in Illinois. Such a system was classified as type 5, a Texas-West Gulf cyclone. Many other systems moved directly eastward from the Pacific Ocean, but these were classified into one of the five source-route types according to the route and area which last contributed to its re-formation or intensification.

Although the vast majority of severe winter storms in Illinois were produced by these five types of transitory cyclones, 14 were associated with certain other synoptic weather conditions. In two cases, frontal passages alone produced the frozen precipitation. Five storms resulted when the cyclone appeared to form in the Great Lakes Basin. Four other severe storms resulted from migratory cyclones that moved in a northerly direction west of the Mississippi River and into the westernmost part of the Great Lakes Basin. In three other instances, wave centers associated with similar transitory cyclones moved diagonally across Illinois into the Lakes region. These infrequent conditions were grouped and considered as weather type 6 in further analyses of the storms.

Climatological analysis of cyclone frequency in the November-April period allows an estimation of the percentage of all cold-season cyclones that result in severe winter storms in Illinois. In table 15, types 2, 3, and 4, which originate in Colorado, have been grouped for comparison with readily available statistics on the frequency of all Colorado cyclones. All cyclonic frequencies were set to a base period of 20 years for ease of comparison. The frequency of Alberta cyclones was determined from a 20-year sample[16]; the 20-year frequency of Colo-

Table 15. Comparison of the Frequency of Cold-Season Cyclones with the Number Producing Severe Winter Storms in Illinois

Cyclone source area	Total number of cyclones developed in average 20-yr period	Number of severe storms produced in Illinois in average 20-yr period	Percent of total cyclones leading to Illinois storms
Alberta (type 1)	487	11	2 +
Colorado (types 2, 3, 4)	640	61	10—
Texas-West Gulf (type 5)	304	25	8 +

rado cyclones was extrapolated from data in a 3-year sampling period[13]; the value for the Texas-West Gulf cyclones was calculated from a 40-year sample.[14]

The percentages shown in table 15 reveal that only a relatively small percentage of all cyclones formed, regenerated, or intensified in the three source areas actually lead to severe winter storms in Illinois. The percentages do show that cyclones from the Alberta source region are considerably less frequent producers of severe winter storms than are those in the other two regions.

Detailed Synoptic Analysis of January 1967 Storm

The greatest frequency of severe winter storms in Illinois was produced by the type 2 cyclone. An example of this type of storm occurred in Illinois on 26-27 January 1967, the storm previously described as very damaging (*see* table 9). A detailed chronological synoptic discussion of this storm[17] is presented to illustrate more clearly the upper- and lower-level atmospheric conditions with this prevalent storm type. This particular storm very closely followed the stages of winter storm development described by Petterssen[11]: "The development at sea level was preceded by a forward march and intensification of an upper cold trough and commenced at the time when the area of positive vorticity advection in advance of the upper trough became superimposed upon the sea level frontal zone."

The description of events which produced this severe winter storm begins with conditions at 0000 CST on 25 January 1967, when a continental arctic air mass entered the United States in eastern Montana. A deep wave moved over the Great Lakes Basin as a continental polar air mass, which had formed in the Intermountain region and moved across the Great Plains area. The stationary front continued to exist along the lee of the Rockies while maritime tropical air over the central and eastern United States produced unseasonably warm temperatures. A very small wave formed on the stationary front in southeastern Colorado in the general vicinity of the point juncture of the three air masses cited above (figure 16). A 500-mb trough located over Nevada, with its associated cyclonic vorticity center having a value of 14, moved east at 34 knots.

By 0000 CST on 26 January (the start of the storm in Illinois), the maritime polar air mass extended over the entire western United States, and was separated from the strong continental arctic air mass over the Midwest and Great Plains (as far south as Oklahoma) by a frontal zone extending along the lee of the Rockies and across the central United States. Maritime tropical air dominated the remaining eastern and southeastern portions of the United States, The point juncture of the three air masses was the wave center with a central pressure of 1007.0 mb, and it was located in east-central Oklahoma (figure 16). The warm front portion of the wave extended up the Ohio Valley and into Canada.

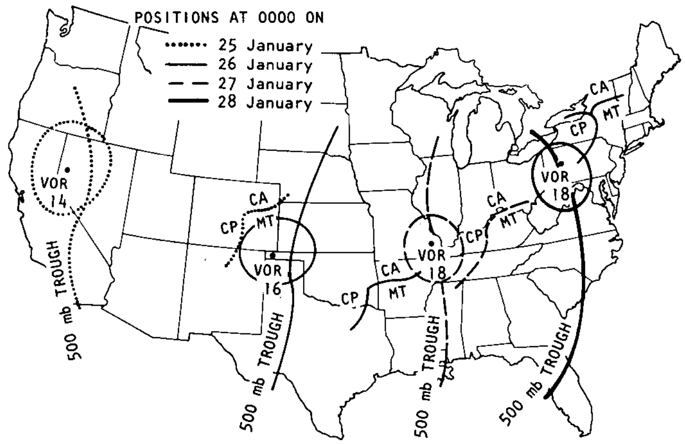


Figure 16. Positions of significant synoptic weather features during 25-28 January 1967

The 500-mb chart at 0000 CST on 26 January showed a deep trough over the Great Plains located about 240 miles west of the surface wave center. An extensive area of snow reached northward over the Great Plains to North Dakota and eastward into Missouri and Iowa. Rain and rainshowers continued to occur along the warm frontal zone in the Midwest. The 1000-mb isobaric contours over Lake Michigan were oriented northeast so that conditions in northeastern Illinois were favorable for lake-effect (added warming and moisture) storms[18] The 500-mb center of cyclonic vorticity with a central value that had increased to 16 was being advected ahead of the trough. Freezing rain in Illinois began shortly after 0000 CST on 26 January, with snow beginning between 0600 and 0900 in the northern areas. Precipitation in excess of 2 inches fell during the next 24 hours in parts of central and northern Illinois.

The wave center moved up the Ohio and was centered near Louisville, Kentucky, at 0000 CST on 27 January (near the end of the storm in Illinois). The wave cyclone dominated the entire central and eastern United States. The cold front portion of the wave extended south through Mobile and was preceded by a squall line. The 500-mb chart showed a closed low in the trough now centered on the eastern Arkansas-Missouri border. The surface wave center pressure had decreased to 997.8 mb, and it continued to be the focal point of the three air masses (figure 16). The center of positive vorticity which had increased to 18 continued to be advected ahead of the upper trough. The storm in various parts of Illinois ended shortly after 0000 CST on 27 January. By 0000 CST on 28 January, the wave had occluded and deepened in the vicinity of Lake Erie.

Frequency of Weather Types

The number of weather types in each month is shown in table 16. The type 2 storm-producing condition prevailed in all months, although type 5 (Texas-West Gulf) was relatively frequent in February. Type 1 (Alberta) was relatively frequent in January.

Table 16. Monthly Number of Weather Types with Severe Winter Storms

Type	Oct-Nov	Dec	Jan	Feb	Mar	Apr-May	Total
1	3	7	13	5	5	1	34
2	9	28	36	24	31	9	137
3	0	5	1	6	8	3	23
4	0	7	7	5	3	0	22
5	5	16	17	21	13	2	74
6	2	2	5	3	2	0	14

Table 17. Number of Weather Types Associated with Different Storm Types

Weather type	Glaze-only, no heavy snow		Heavy snow, no glaze		Henvy snow, plus glaze	
	Number of storms	Percent of total	Number of storms	Percent of total	Number of storms	Percent of total
1	3	9	27	80	4	11
2	17	12	89	65	31	23
3	3	13	13	57	7	30
4	1	5	19	86	2	9
5	6	8	55	74	13	18
6	4	29	9	64	1	7

The frequency of different weather types with the three basically different types of severe winter storms is shown in table 17, and the percentages allow evaluation of the importance of each type. Weather types 1 and 4 were more frequently associated with the heavy snow (no glaze) type of winter storms than were the other weather types. Weather types 2 and 3 were alike in that they both had a distinct tendency for a more frequent association with the glaze-only and the snow-plus-glaze storms than did the other weather types. Weather type 6 had a much higher percentage of association with the glaze-only storms than did types 2 and 3, but type 6 had little association with the snow-plus-glaze storm type.

The frequency of the six weather types with all 304 storms and with the three main categories of damaging storms is shown in table 18. The frequencies for each weather type were expressed as percentages of the total per type to allow evaluation of the relative importance of each weather type for each damage class. The percentages for types 4 and 2 show the relative importance for their associated storms to produce extreme damage. Weather types 1 and 6 are more important than other types in producing storms of moderate damage. The 5 and 3 weather types show a stronger tendency for association with storms producing only minor damages than do the other types. The type 2 and 4 weather conditions which most often led to storms producing extreme damages in Illinois are both conditions with Colorado lows that have either an east track or south track across the Midwest.

Table 18. Frequency of Weather Types Associated with Storms with Different Degrees of Damage

Weather type	Extreme damage		Moderate damage		Minor damage		All storms*	
	Number	Percent of total	Numler	Percent of total	Number	Percent of total	Numler	Percent of total
1	4	24	5	29	8	47	34	11
2	31	38	15	18	36	44	137	45
3	5	28	4	22	9	50	23	8
4	4	40	2	20	4	40	22	7
5	11	31	4	11	21	58	74	24
6	3	30	3	30	4	40	14	5

**Includes storms with no damages or unknown damages*

Effect of Lake Michigan on Severe Winter Storms

Lake Michigan occasionally plays a role in the occurrence or intensification of severe winter storms in northeastern Illinois. In these instances, the migratory cyclone which produces the severe storm has a trajectory such as to orient its isobaric contours cyclonically from southeast through north. Such an orientation occurs when the wave center passes south and east of Illinois (types 2 and 5). This route produces low-level winds from east through northwest, but the more northerly winds have the longest fetch across Lake Michigan. The warmer wintertime open water adds 1) a significant amount of heat to the cold air mass passing over the lake and 2) moisture to relatively dry air, both of which can act to enhance snowfall in northern Illinois.

To examine for the possible effect of Lake Michigan on the occurrence or intensification of severe winter storms, the mean isobaric orientations at the 1000-mb level over the lake during the storm period were determined for all 269 storms having more than 6 inches of snow. Nine orientations and rapidly changing cyclonic and anticyclonic configurations were found. Overlake flow towards Illinois (orientations of NNE, NE, ENE, and E) occurred in 164 storms, cyclonic in 27, anticyclonic in 8. Overlake orientations which should not affect Illinois (NW, NNW, N, ESE, and SE) occurred with 105 storms. In general, the gross effect of moisture influx from the Atlantic Ocean and the Gulf of Mexico predominated and obscured any significant lake effect on most of the storms,

Certain indications of lake effect are shown in the area1 distribution of 6-inch snowfall cores (figure 17). The frequency pattern for the storms with the favorable overlake isobaric orientations (figure 17a) showed much more latitudinal variation with the two northern sections experiencing cores 2 to 3 times more often than did the southernmost districts of Illinois. With no overlake flow, the northern districts had only 1.2 to 1.5 times more heavy snowfall cores.

The storms with overlake flow represented 54 percent of all storms. There were 65 storms with a maximum point snowfall of 12 inches or more, and 52 of these (70 percent) occurred with overlake isobaric orientations. These facts suggest an intensification of snowfall in Illinois with overlake flow.

A total of 31 winter storms had snowfall maximums in close proximity to the lake and restricted to the near-lake area. These patterns appeared to be a direct result of lake effects.[18] Ten of these storms had only one maximum,

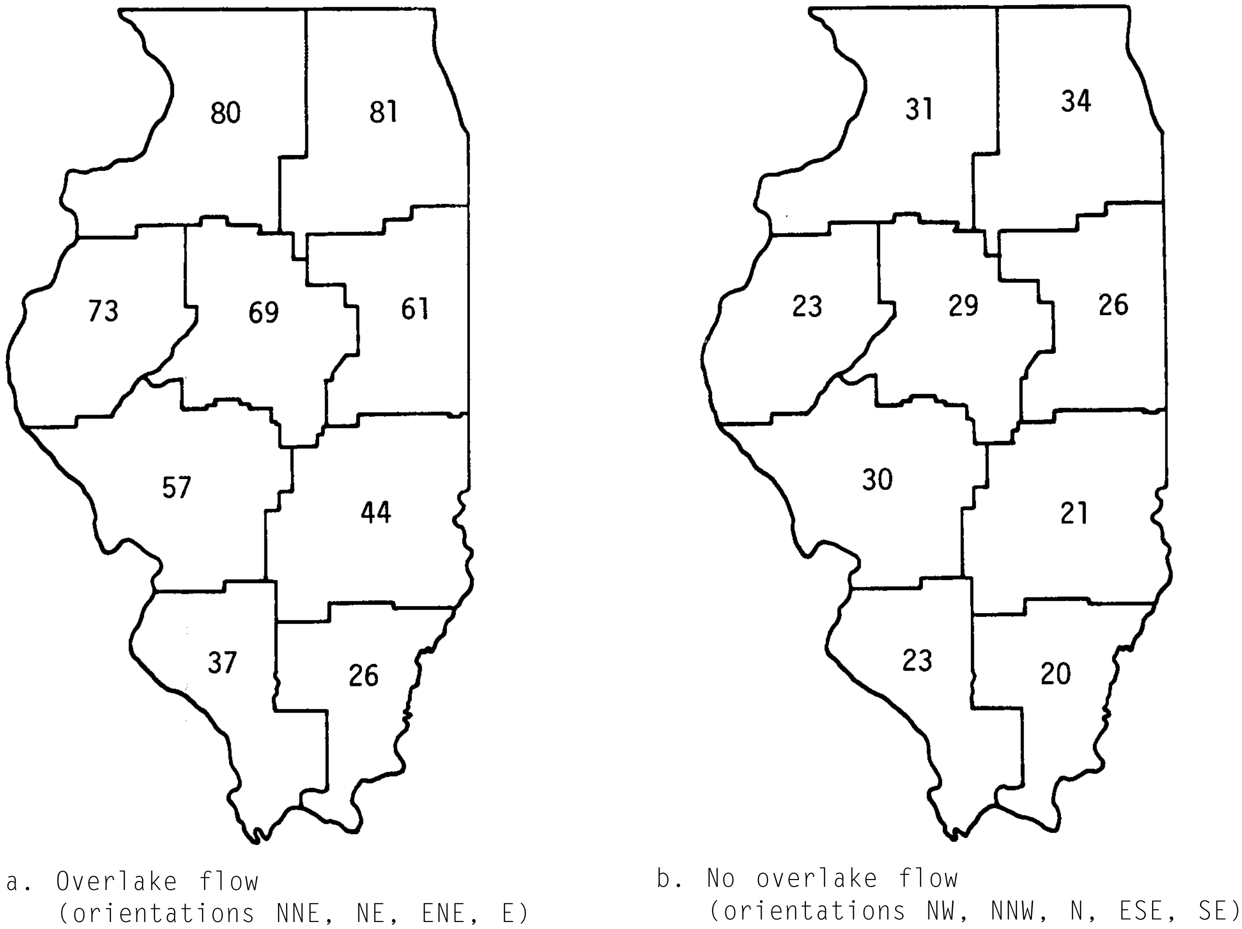


Figure 17. Number of times 6-inch snow cores occurred in each district (1900-1960) with different 1000-mb isobaric orientations over Lake Michigan

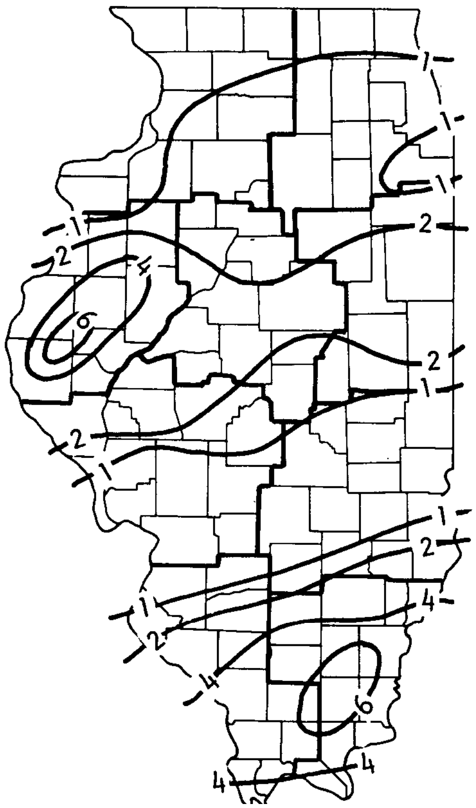
that at or near the lake, and would not have qualified as severe winter storms without the lake effects. The 21 others had a lake-produced maximum and one or more cores elsewhere in Illinois. Thirteen of these storms reflecting strong lake effects occurred in November and December, when the lake water is relatively warm, [19] providing a source of heat as well as moisture. The lake-effect snowstorms assume importance in Illinois because they occur in the complex Chicago urban area where 6 inches or more snowfall in 48 hours or less is a relatively more serious problem than it is elsewhere in Illinois.

PATTERNS OF SELECTED WINTER STORMS

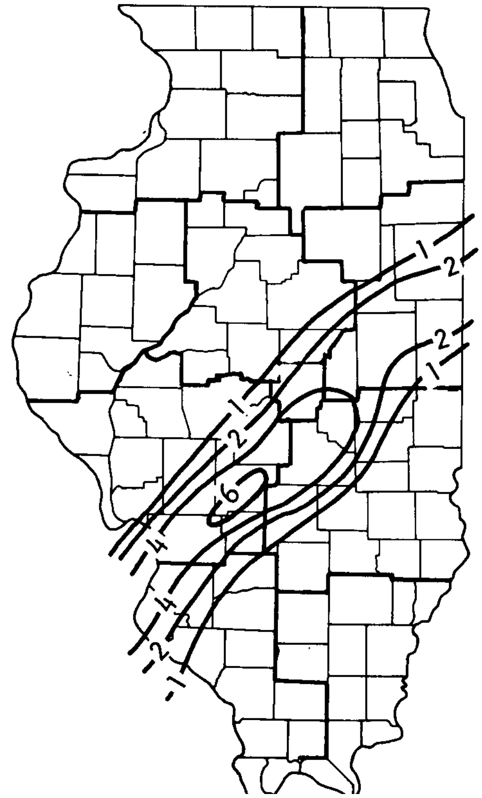
Certain unusual winter storms or storms occurring in unusual circumstances have been portrayed in this section to illustrate their patterns. The patterns for the earliest (28-30 October 1925) and latest (l-2 May 1929) winter storms are shown in figures 18a and b. Neither storm produced any glaze in Illinois nor even minor damages (less than $1000). The May storm was not extensive and had a very narrow path across Illinois. Figure 18c illustrates the pattern of a storm oriented NW-SE across Illinois, one of the three storms with such an orientation. Figure 18d illustrates another infrequent type of winter storm. In this ‘southern’ storm, the core is just barely located in extreme southern Illinois.

Figure 19 presents six storm patterns illustrating lake-effect heavy snowfalls in northeastern Illinois. Figures 19a, b, and c show 3 of the 10 lake-effect storms with a single maximum in the state. In figure 19a, the maximum is inland and southwest of the lake; in figure 19b, the maximum is small and located on the lakeshore; and in the third example, the maximum is inland and west of the lake (figure 19c).

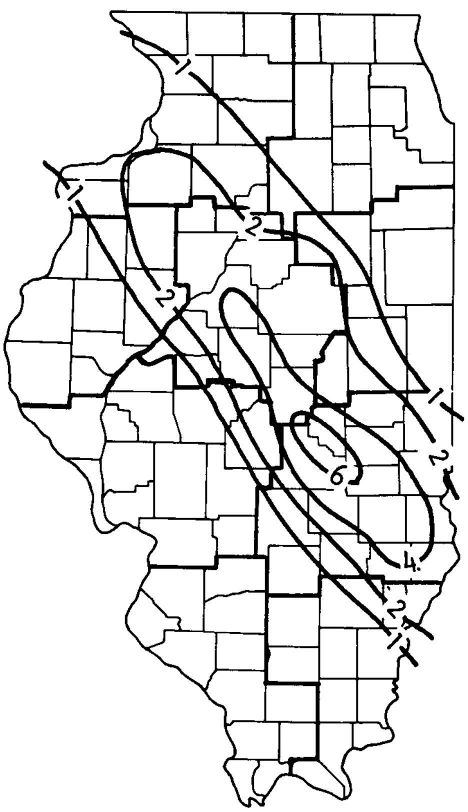
Figures 19d, e, and f are examples of the 21 storms with a lake-effect maximum in addition to maximums elsewhere in Illinois. These storms would have achieved a severe classification without the lake-effect high, but the lake did produce heavy snow in northeastern Illinois. The shape of the high near the lake in figure 19d is similar to that in figure 19b. The lake-effect maximum shown in figure 19e exhibits still another pattern, with a narrow ridge parallel to and extending along the entire



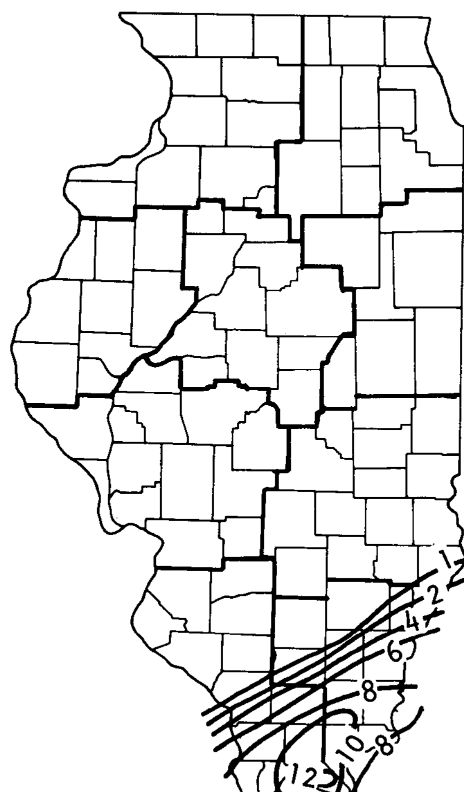
a. Earliest storm of season,
28-30 October 1925



b. Latest storm of season,
1-2 May 1929



c. Storm with NW-SE orientation,
27 November 1922



d. Storm centered in south,
2-3 February 1939

Figure 18. Examples of snowfall patterns for unusual storms

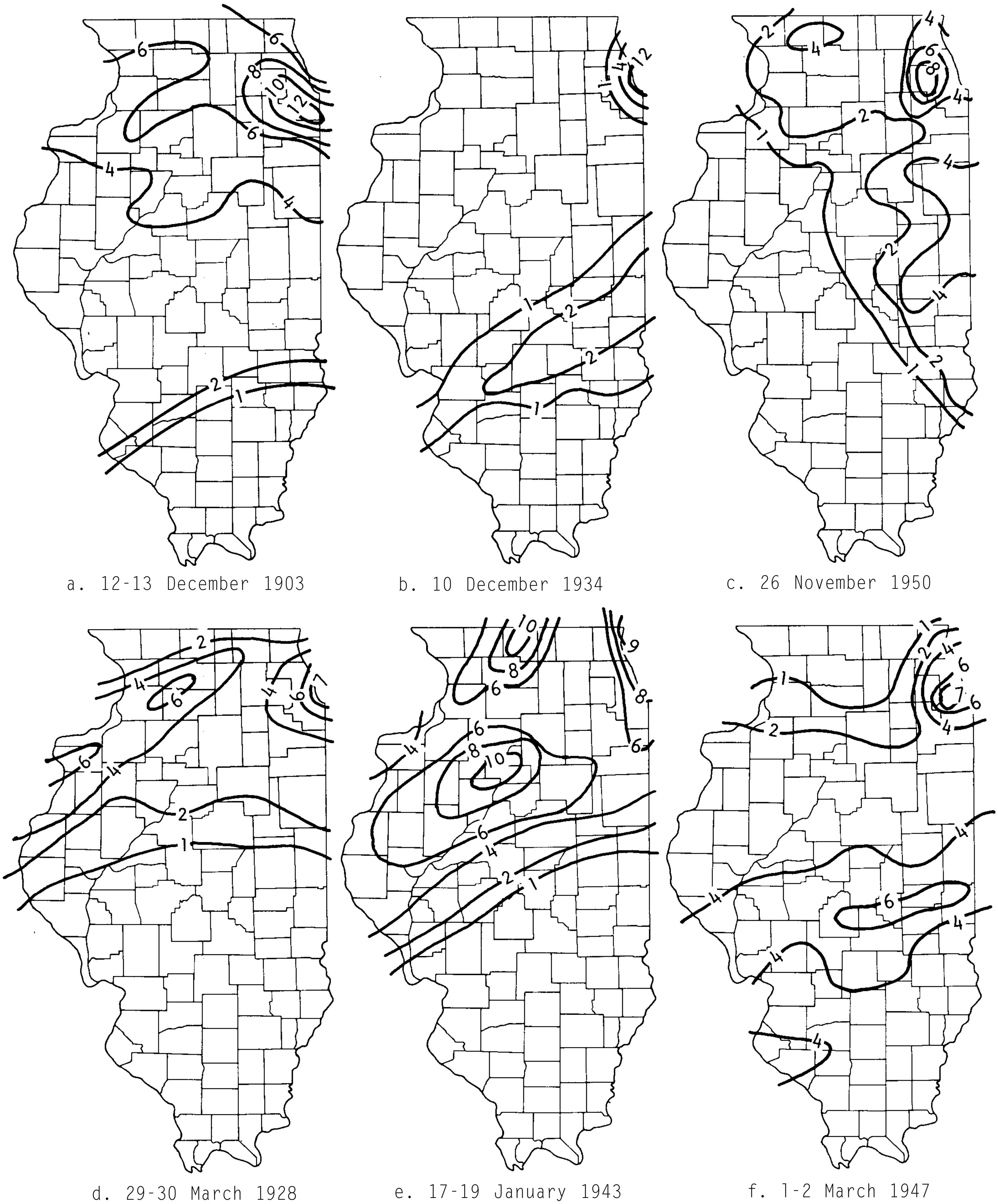
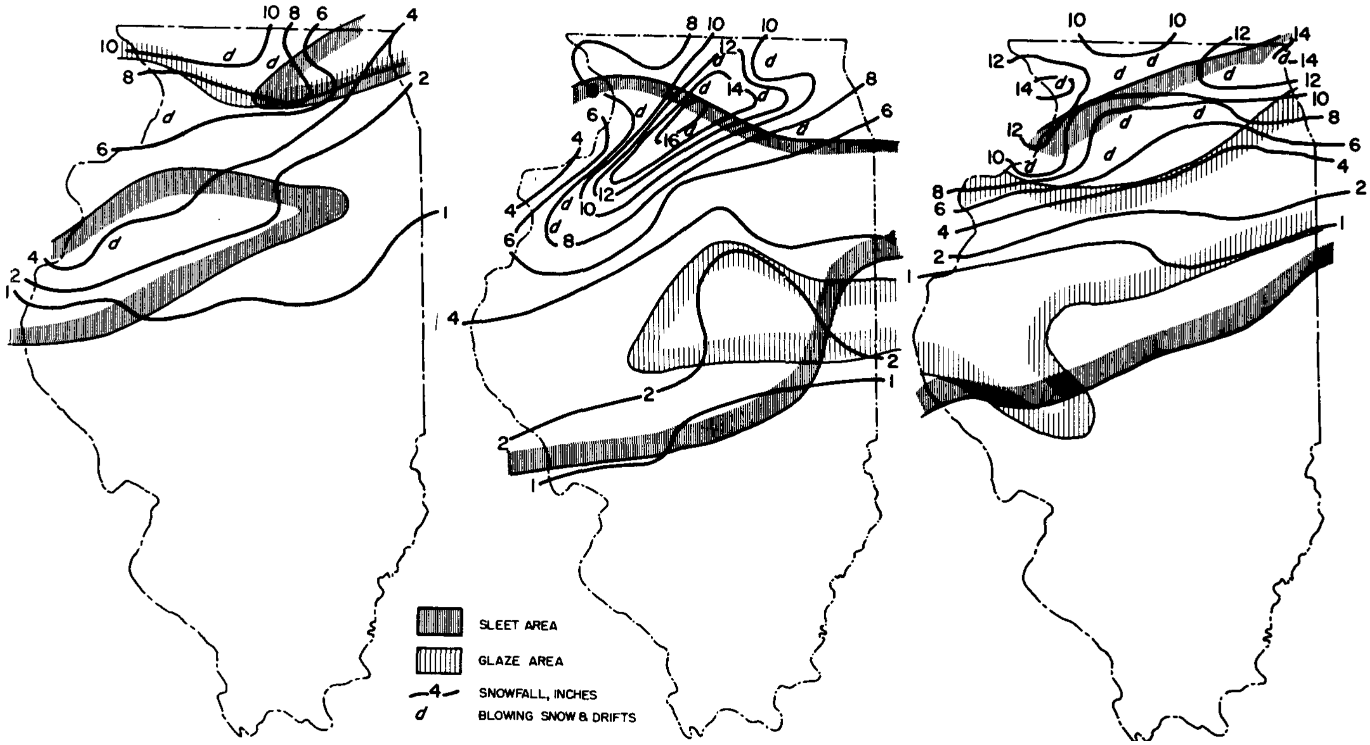


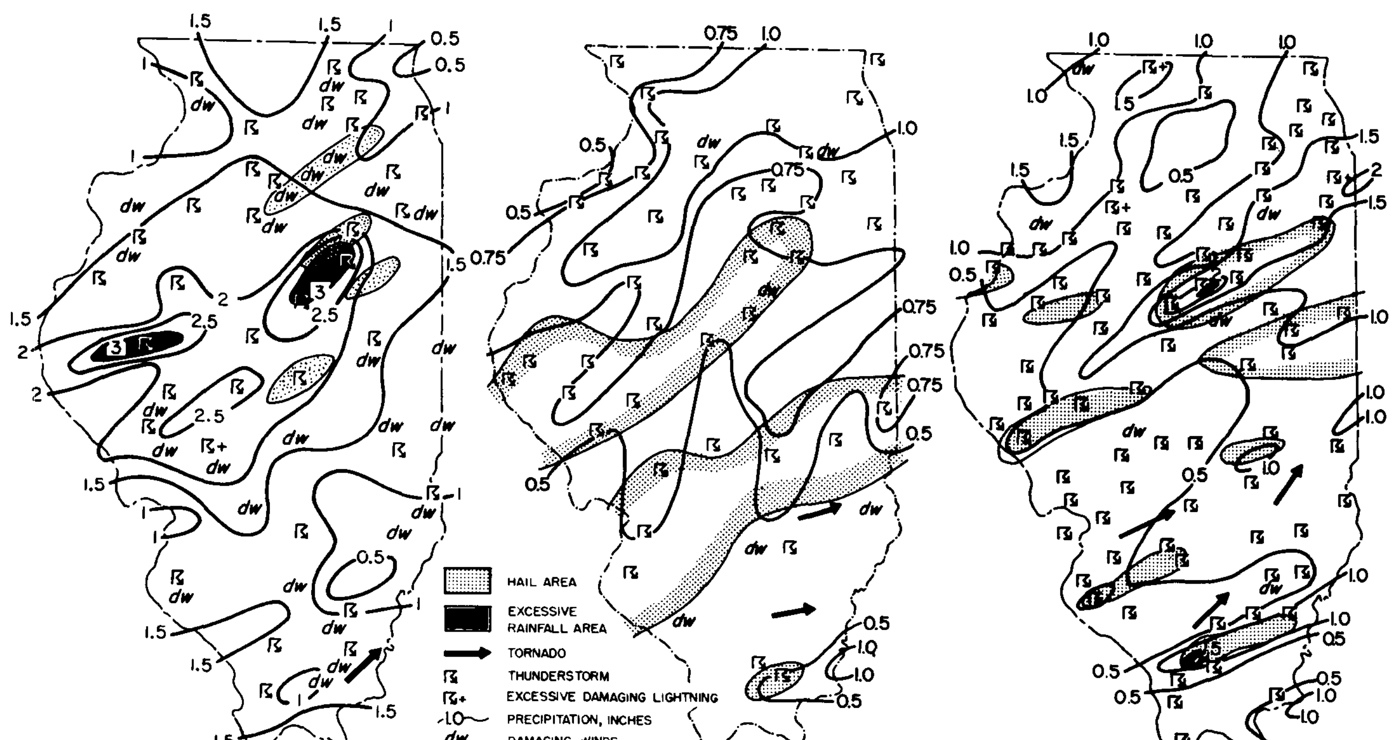
Figure 19. Examples of storm snowfall patterns reflecting lake effects

lakeshore in Illinois. Figure 19f shows an isolated high westward and inland from the lake, but it is not centered in the same location as that of the high in figure 19c. The location of the heavy snowfall center resulting from flow over Lake Michigan varies and is dependent on the orientation of the flow (length of overlake travel), wind



Snowfall, glaze, sleet, and blowing snow on

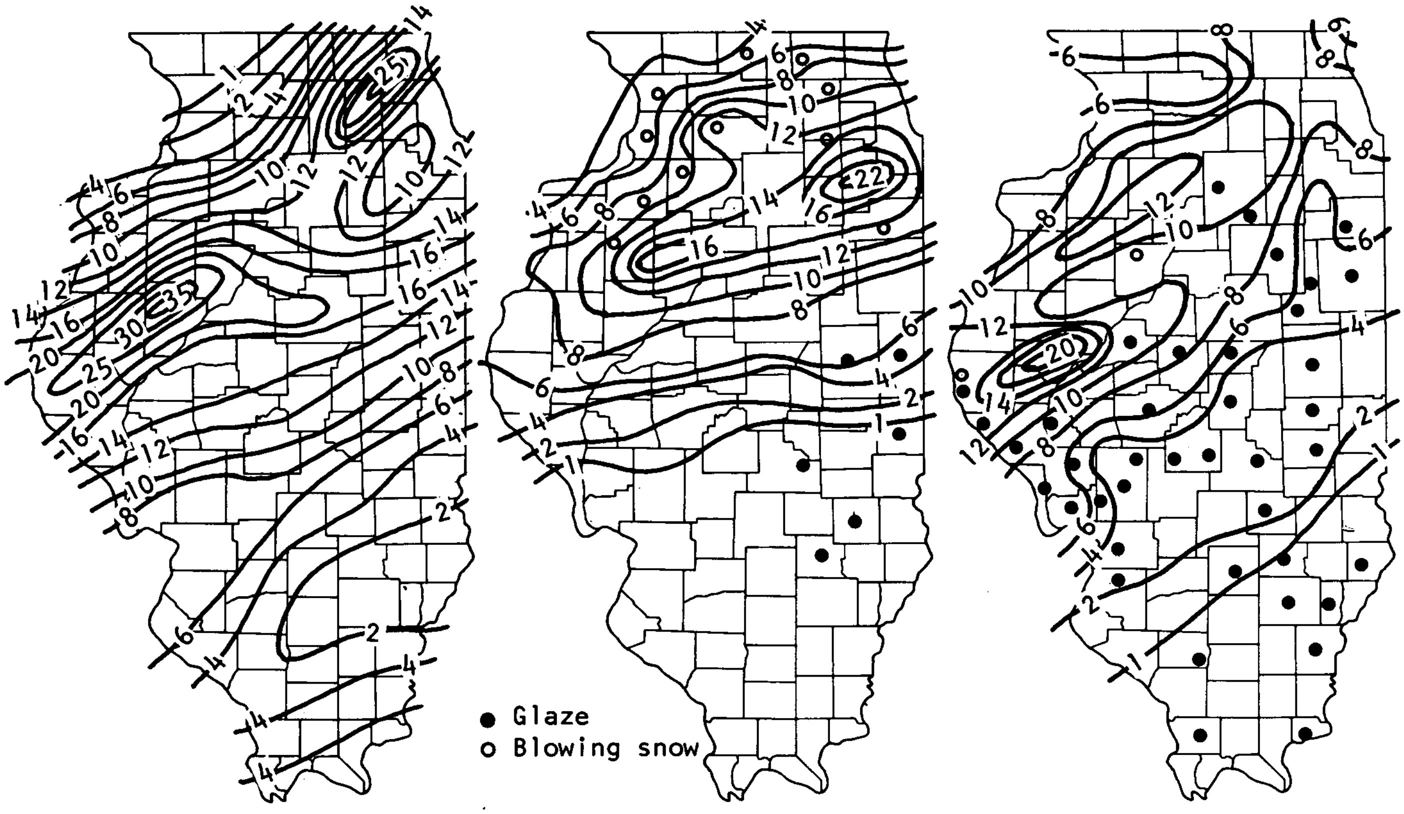
a. 11-12 March 1923 b. 20-21 March 1932 c. 9-10 February 1960



Thunderstorms, hail, damaging lightning and winds, precipitation, excessive rainfall, and tornadoes on

d. 11-12 March 1923 e. 20-21 March 1932 f. 9-10 February 1960

Figure 20. Patterns of three freak winter storms



a. 27-28 February 1900 b. 6-8 February 1933 c. 20-22 January 1959

Figure 21. Three winter storms producing the heaviest point snowfalls in 1900-1960 period

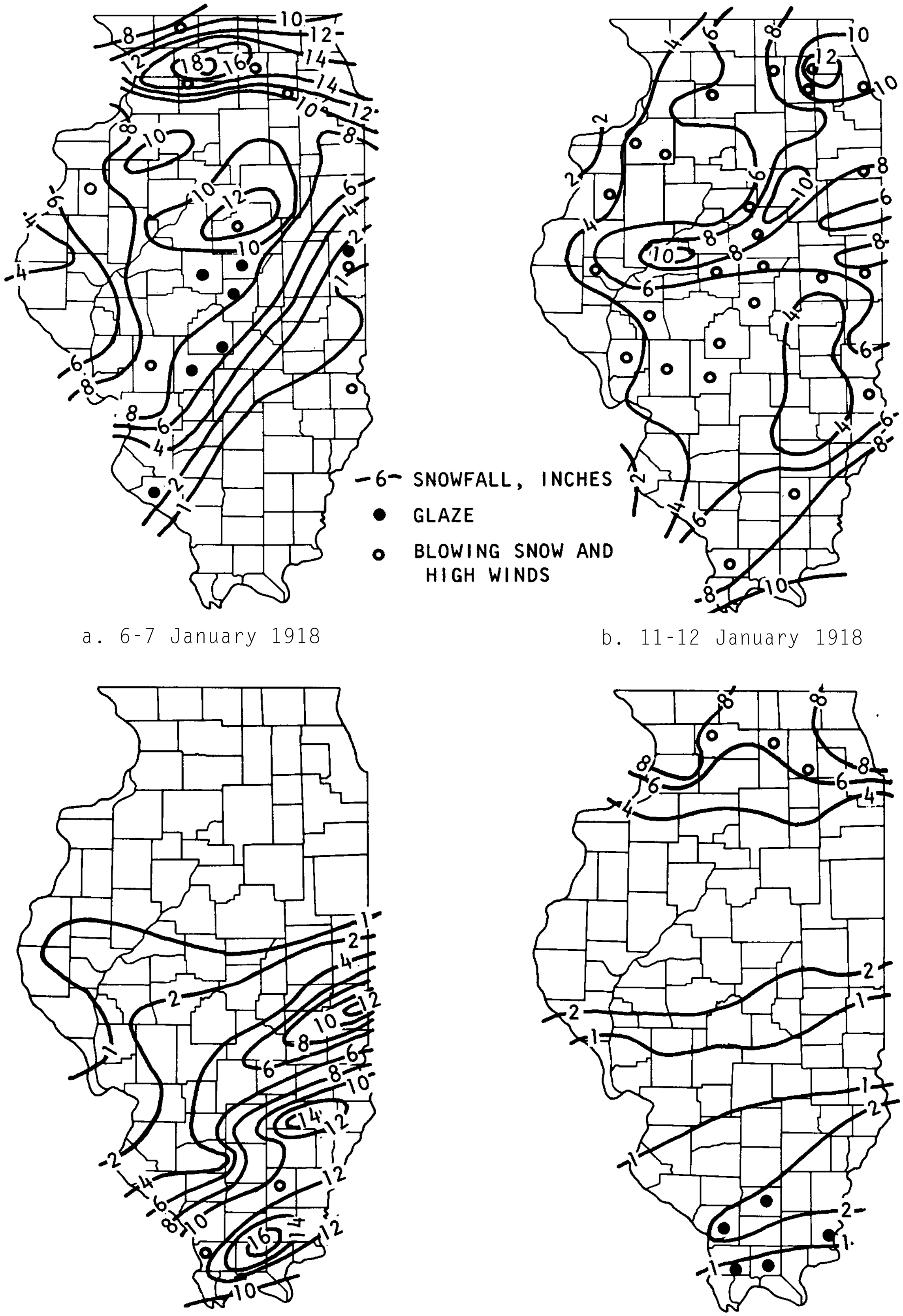
speed, and relative differences between the temperature and humidity of the air and that of the lake and land just downwind of the lake.[18]

Three other severe winter storms were quite unusual because they each combined the occurrence of heavy snow, high winds, damaging-widespread glaze, sleet, thundérstorms, hailstorms, and tornadoes in Illinois.[20] Their patterns (figure 20) reveal a general latitudinal distribution, with the severe weather events common to the warm season largely in central and southern Illinois. However, many persons in the 1932 storm had the unusual experience of witnessing a lightning storm while heavy snow was falling. All three storms caused sufficient damage to be in the extreme damage class, and two (1923 and 1960 storms) were ranked as the 9th and 19th worst storms respectively (table 14). All three storms were produced by weather type 2, the most common type. Studies of midwestern snowstorms have shown that thunderstorms embedded in a snowfall zone could increase local falls by 2 inches or more if the thunderstorm persisted for 3 hours.[21]

The patterns of the three storms producing the highest point snowfalls in the 1900-1960 period are shown in figure 21. The 37.8-inch maximum in western Illinois on 27-28 February 1900 was considerably greater than that in the storm with the second highest value, 22.1 inches in the 6-8 February 1933 storm. (As a comparison, the more recent 26-27 January 1967 storm had a point maximum of 26.0 inches, at Peotone just south of Chicago, which would place it second after the 1900 storm.) The point maximum in the 1959 storm in figure 21 was 21.5 inches. The 1900 storm had two areas with snowfall in excess of 25 inches and was extremely damaging. The 1933 storm caused only minor damages, but the 1959 storm caused extensive damages, being ranked as 13th.

The greatest number of badly (moderate or extreme) damaging storms in one month was four in January 1918. The patterns of these storms appear in figure 22. The storms on 6-7 and 11-12 January were both classed as extremely damaging, ranking as the 17th and 2nd most damaging in the 1910-1960 period, respectively (table 14). The storms on 14-15 and 26-28 January produced damages in the moderate class. All four storms were basically 'snow-only' storms, and only the 6-7 January storm rated also as a glaze storm. At the end of January 1918, the snow on the ground in Illinois was 35 inches in northern Illinois, 10 to 20 inches in the central districts, and 7 to 10 inches in southern Illinois.

The greatest number of badly damaging storms in Illinois in a 2-month period occurred in 1951-1952. Six storms occurred in a 58-day period beginning with a storm on 6-7 November 1951. The patterns of these six storms are shown in figure 23. The storms on 6-7 November, 25 December, and 1-2 January all were extremely damaging and the other three were moderately damaging. A minor damaging storm occurred on 17-18 January also.



a. 6-7 January 1918

b. 11-12 January 1918

c. 14-15 January 1918

d. 26-28 January 1918

Figure 22. Severe winter storms in January 1918

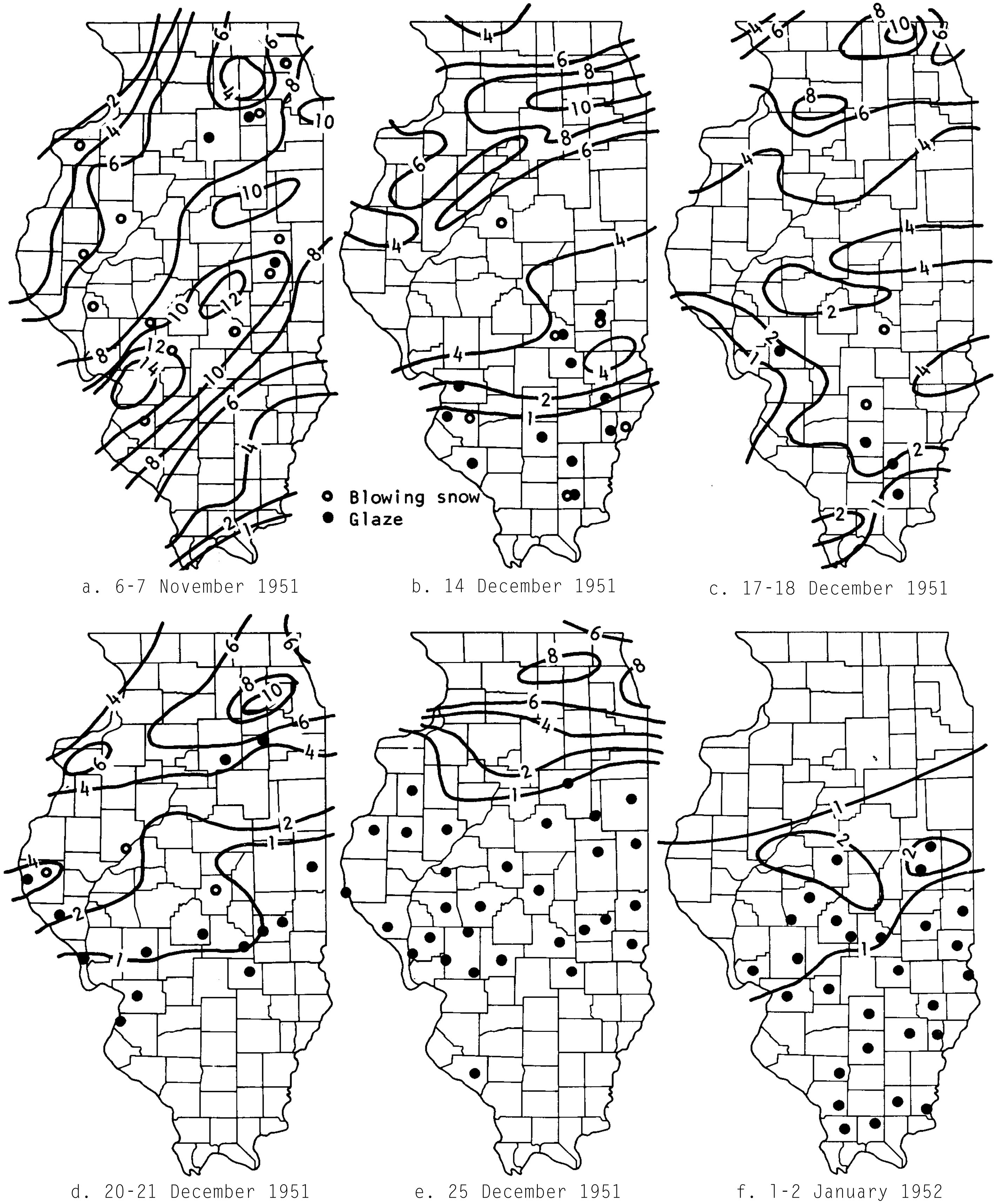


Figure 23. Series of six damaging storms in 58-day period

Part 2. Climatography of Glaze Storms

Glaze-producing (ice) storms in the 1900-1960 period were selected for separate study because their damage-producing capability and related design problems are significantly different from those associated with snow. In the 61-year period there were 92 glaze storms defined either by the occurrence of glaze damage or by occurrence of glaze over at least 10 percent of Illinois (as determined by station density), and these 92 represent 30 percent of the total storms. Thirty-four of these glaze storms were solely glaze storms and occurred without any 6-inch snowfalls in Illinois, whereas the other 58 were associated with heavy snowfall. Sixty-nine of the remaining 212 storms had some glaze reports but no glaze damages and too few point reports of glaze to qualify as widespread glaze (10 percent of Illinois; *see* table 7). The study of glaze storms was restricted to the 92 storms qualifying as damaging, widespread, or both.

TEMPORAL CHARACTERISTICS

Annual Frequencies

The number of severe winter glaze storms in Illinois during an average 10-year period is 15, but there have been as many as 28 storms in a 10-year period, (1944-1953), and as few as 9 (1902-1911). The greatest number of glaze-producing storms in one year was 6 (1951); in two years, 9 (1950-1951); in three years, 10 (1950-1952); and in five years, 15 (1948-1952). There were no glaze storms in 12 of the years during 1900-1960.

Monthly Frequencies

The total number of storms in each month is shown in table 19. The greatest numbers occurred in December and January, and these represented slightly more than one-third of all severe winter storms in these two months, The number of winter storms in February, March, and April that were glaze storms are quite comparable, 28 or 29 percent. Percentages in table 19 reveal that relatively few of the November winter storms produced damaging glaze or widespread glaze.

Table 19. Monthly Number of Glaze Storms

Conditions	Nov	Dec	Jan	Feb	Mar	Apr	Total
Glaze-only (no heavy snow)	1	10	10	4	8	1	34
Glaze with heavy snow	2	12	17	14	10	3	58
Total	3	22	27	18	18	4	92
Number of glaze storms as a percent of all winter storms	17	35	34	28	29	29	30

Time of Occurrence

The time that each glaze storm initiated in Illinois could be determined for 85 of the 92 glaze storms. The number of initiations in each of the six 4-hour periods of the day is shown in table 20. The glaze-only storms showed a preference for initiation in the 0801-1200 CST period, whereas the glaze-plus-heavy-snow storms showed almost equal numbers of initiations in the three 4-hour periods beginning after 0800.

Table 20. Number of Glaze Storm Initiations in 4-Hour Periods

Conditions	Time, CST 0000–0400	0401–0800	0801–1200	1201–1600	1601–2000	2001–2400
Glaze-only (no heavy snow)	5	5	10	6	3	3
Glaze with heavy snow	8	7	13	11	11	3
Total	13	12	23	17	14	6

Storm Point Durations

The average point storm duration could be determined for 82 of the 92 glaze storms. The values ranged from a low of 2 hours to a high of 48 hours. The median point duration of the glaze-only storms was 12.0 hours, and that of the glaze with heavy snow was 13.1 hours. Both values are less than the 14.2-hour median determined for all storms (table 5). Only 14 of the 82 glaze storms with discernible durations had point durations greater than 20 hours, and 11 of these were storms with glaze and heavy snow. There was little difference between the median durations determined for each month.

Geographical Distribution of Glaze Areas

The geographical location (figure 24) of glaze was recorded as being in the north, central, south, north and central, central and south, and all three areas (north, central, and south). Twenty-one glaze storms occurred over all three areas (table 21), and the second largest number, 18, occurred in only the central area.

Table 21. Number of Glaze Storms in Various Areas of Illinois

Areas	Nov	Dec	Jan	Feb	Mar	Apr	Total
North	1	1	1	2	6	2	13
Central	1	5	5	2	3	2	18
South	0	4	2	4	2	0	12
North and central	0	3	5	4	4	0	16
Central and south	0	2	7	2	1	0	12
North, central, and south	1	7	7	4	2	0	21

In December and January, the 3-area occurrences predominate, with a considerable number of occurrences for the central area and for the southern area. In March, April, and November, glaze occurrences were predominantly in northern and central Illinois.

The monthly and total number of times a glaze region occurred in each area are depicted in figure 24. The central area totals equal or exceed those of the other areas in all months except March. Southern totals rank second in December, January, and February; northern experiences rank second in February (ties south), and first in March, April (ties central), and November (ties central). These monthly values show a northward shift with time in severe glaze occurrences during the winter season. The winter totals for each of the three areas (figure 24) indicate that the greatest frequency was in central Illinois with frequencies in southern and northern Illinois being nearly equal.

Other maps of the areal distribution of glaze storms, as defined by different sets of data,[7] are shown in figure 25. Three of these maps show a latitudinal distribution with the most occurrences somewhere in northern Illinois and the fewest in southern Illinois. However, the pattern on figure 25d, based on railroad measurements of ice on wires, shows a central Illinois maximum which agrees with findings from this study (figure 24). The differences between the patterns in figures 25a, b, and c and that in figure 24 are considered to result from the different sampling periods. The 61-year period should provide a more representative measure than the 9- to 28-year periods.

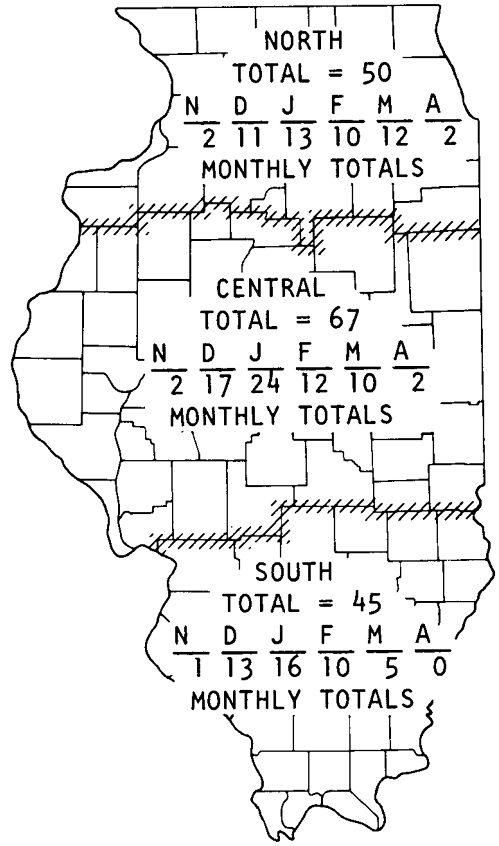


Figure 24. Number of times glaze occurred in each area on days with glaze storms, 1900-1960

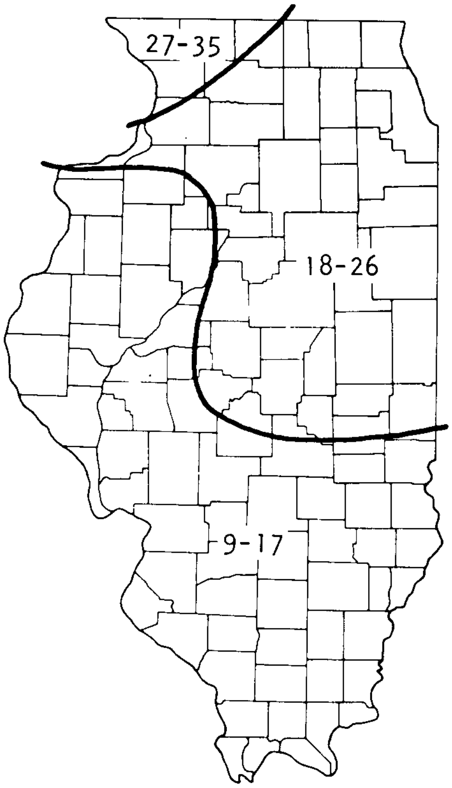
Areal Extent of Glaze Areas

The percent of Illinois experiencing glaze was determined for each of the 92 storms with widespread glaze, or damaging glaze, or both. The percentages were determined from the number of stations reporting glaze by allowing each of these to represent a given portion of Illinois. This portion varied depending on the total number of weather stations existing in Illinois in the year of the storm (*see* page 5). The storm percentage values were used to calculate monthly average percentage values (table 22). The averages reveal that glaze areas were most widespread in January and December, and considerably less widespread in the other four months.

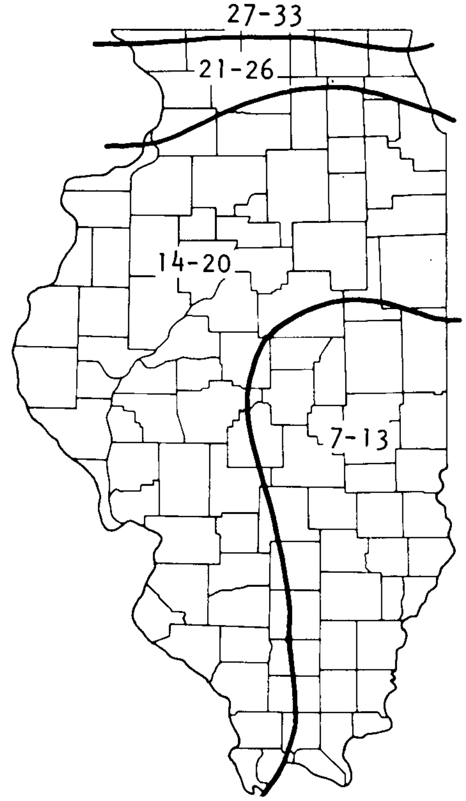
Table 22. Areal Extent of Glaze in Glaze Storms

Storm area	Percent of Illinois with glaze per storm						
	Nov	Dec	Jan	Feb	Mar	Apr	All
Average	6.3	18.5	20.7	11.6	8.7	10.7	15.1
Maximum	11	46	43	32	28	25	46
Minimum	1	4	2	1	1	2	1

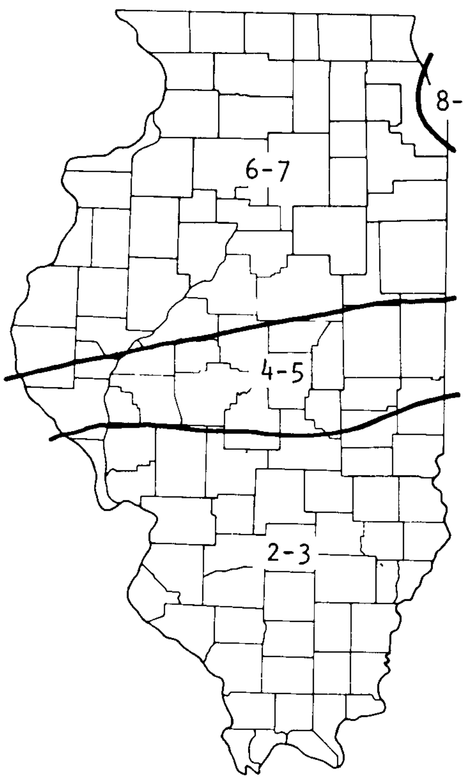
The six storms in the 1900-1960 period with the most extensive glaze areas are shown in figure 26. These patterns reveal the shape and size of glaze areas when glaze



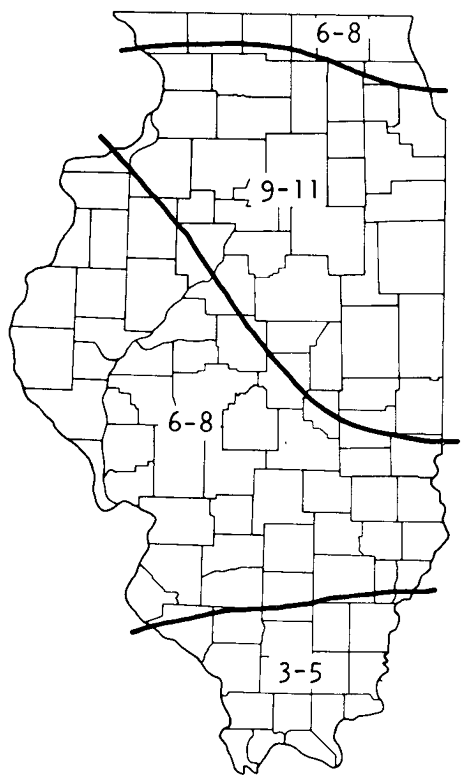
a. Number of glaze storms in 1929-1937, Association of American Railroads data



b. Total severe glaze storms in 1925-1953 from U. S. Weather Bureau data



c. Glaze storms causing damage to telephone wires and poles, 1918-1925



d. Storms with 0.25” or more radial thickness of ice on railroad wires, 1929-1937

Figure 25. Patterns of glaze storm frequencies as depicted by data from different agencies and for different base periods

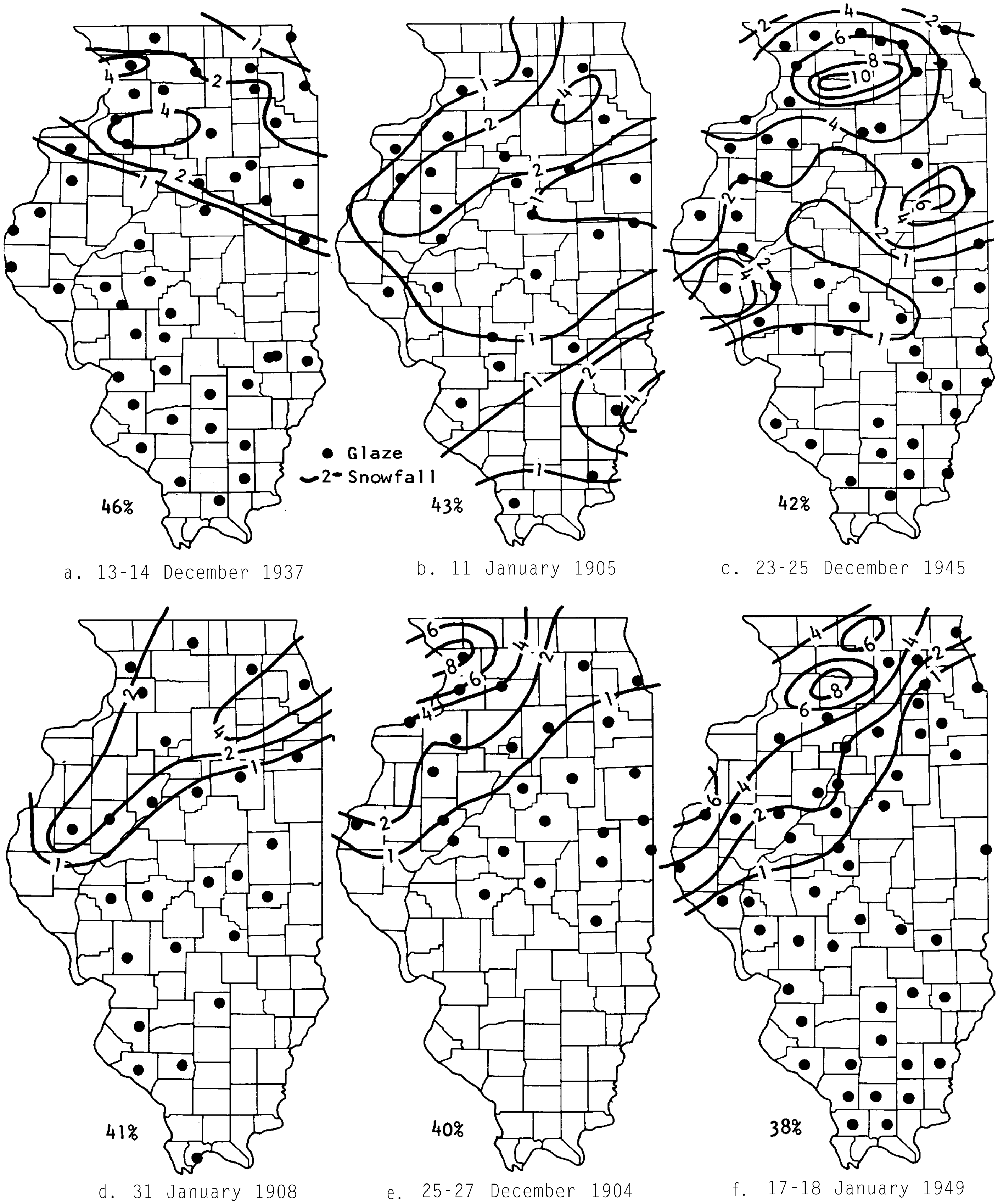


Figure 26. Six storms in 1900-1960 with most extensive glaze areas, and percent of state covered by each

is extensive in Illinois. All produced damaging glaze, and were ranked as either moderately or extremely damaging storms, as based on total damages. The 1949 storm in southern Illinois produced considerable tree damage on the valuable forests and fruit orchards of that area.[22]

Motion of Storms

The motion of the glaze-producing storms across Illinois could be determined for 86 storms. The number sorted into 30-degree sectors (table 23) revealed that the maximum number of storm motions were in the 241-270 degree sector (WSW), with minor maximums in the 151-180 (SSE), 211-240 (SW), and 301-330 (NW) degree sectors. The glaze-only storms exhibited a maximum of motion from the SW (211-240 degrees), whereas the glaze with heavy snow moved most often from the WSW.

Table 23. Directions from which Glaze Storms Moved Sorted into 30-Degree Sectors

30-degree sector	Number of storms: Glaze-only	Glaze with heavy snowfall	Total
121-150	1	4	5
151-180	6	4	10
181-210	3	2	5
211-240	12	3	15
241-270	5	26	31
271-300	3	3	6
301-330	4	5	9
331-359	0	5	5
Total	34	52	86

Orientation of Glaze Areas

The general shape of the glaze areas could be determined for 62 of the glaze storms. These areas tended to be elongated. The long axis of 50 of these areas (80 percent) had orientations varying from 225 to 260 degrees (SW-NE through WSW-ENE). Eight other glaze area orientations were in the 261-280 degree sector, and four were in the 180-224 degree sector.

METEOROLOGICAL CONDITIONS WITH GLAZE STORMS

Seven glaze storms (8 percent) occurred with Alberta lows (type 1), and 48 (52 percent) occurred with Colorado lows having a southerly track (type 2). Only 42 percent of the snow-only severe winter storms were produced by the type 2 conditions, revealing that weather type 2 not only leads in glaze storm production but is relatively more important in producing damaging or widespread glaze than in producing 6-inch or greater snowfalls. Ten of the 92 glaze storms were with type 3 cyclones (figure 15), 3 were type 4, 19 were type 5, and 5 resulted from other weather conditions grouped as type 6.

Riehl[23] indicated that most Illinois glaze storms occur during the northeastward advance of a low center (types 2 and 5), and are quite uncommon with lows that move eastward (type 4) or southeastward (types 1 and 3). He defined two kinds of glaze storm situations: 1) a polar front wave moving northeast along the eastern edge of a continental polar outbreak, and 2) a broad southwesterly current ascending over a sluggish body of cold air in the eastern United States.

In weather types 2 and 5, a warm front frequently lies across Illinois with the rain-producing maritime tropical air overrunning the narrow wedge of cold polar air below it, and this combination of circumstances is necessary for glaze formation. In a synoptic analysis of 12 ice storms at Springfield, Illinois, Bennett[7] found that seven storms came with warm fronts, three with cold fronts, one with no front, and one with an occlusion.

Another analysis of severe glaze storms in the Upper Mississippi Valley showed that only 27 percent were from the Texas-West Gulf area,[7] which agrees with the 21 percent (19 out of 92) found for type 5 in Illinois. Bennett also concluded that a major number of glaze storms in the Illinois area were Colorado lows with a southward track (type 2). His findings on storms produced by lows from the west or northwest (types 1 and 3) showed that 20 percent were of these types. This agrees with the 19 percent for types 1 and 3 given in table 17, but disagrees with Riehl's conclusions.[23]

Part 3. Design Information

Various point and area data on snowfall, glaze, and related conditions were analyzed to provide 1) answers to questions of structural design affected by these conditions and 2) information relating to various commercial operations affected by these severe conditions. Selection of the information presented was based largely on the type of requests for information received, prior studies, and on the obvious problem conditions.

The first phase of this design section concerns point data. Included are point frequencies of heavy snowfall, maximum point snowfalls on record, maximum annual and storm snowfalls in Illinois, maximum point snow-depth values, point glaze-day frequencies, maximum point glaze accumulations, glaze with wind relationships, frequency of days with snowfalls of different magnitudes, and frequency of days with sleet.

The second phase of the design section concerns various areal-geographical conditions. Included are area-depth snowfall relationships for the severe winter storms, models of snowstorms and glaze storms, regional probabilities of snow and glaze storms, temporal probabilities for the occurrence of a storm after one has occurred, and data on the temporal persistence of heavy snow and glaze in the storm center after a storm.

POINT DATA

Point Frequencies of Heavy Snowfall

For the study of various point frequencies of short-term, heavy snowfall, data from 23 stations (figure 27) with 61-year records were analyzed. Point values for clock-hour periods of 24 hours or less could not be discerned at the 17 substations because their snowfall data were recorded only once daily and at the same time every day. Therefore, this analysis was based on fixed 2-day (calendar) totals, which in many instances do not represent 48-hour maxima. However, at most stations at least 30 percent of the 25 heaviest 2-day totals in the 61-year period were values recorded for only one calendar day with no snowfall on the days before or after it. The 2-day values were amounts that likely fell in less than 24 hours in many instances since median point severe storm durations were less than 15 hours (table 5). A similar analysis was based on maximum snowfall values for 7-day (calendar) periods.

The highest 25 values for 2-day and 7-day periods at each station were ranked and used to derive frequency distribution curves. From these curves, values for various return periods ranging from 2 to 50 years were ascertained. These values for each station were compared with all other station values to determine which stations had similar recurrence interval values. Five areas (figure 27) of similar recurrence interval values were found. The 2-day station values in each area were averaged to determine the area mean values shown in table 24; values determined for 7-day periods are shown in table 25.

The 2-day area-average curves in figure 28 reveal that area 3 has lower values than area 2 at the 2- and 5-year intervals, but the area 3 values exceed those in area 2 at the less frequent recurrence intervals. Area 4 in the south has higher expected values at intervals beyond 25 years than has area 2, which is farther north. Areas 3, 4, and 5 all have 50-year values that are almost equal. Area 1 in northern Illinois has much higher values at all intervals than the other areas.

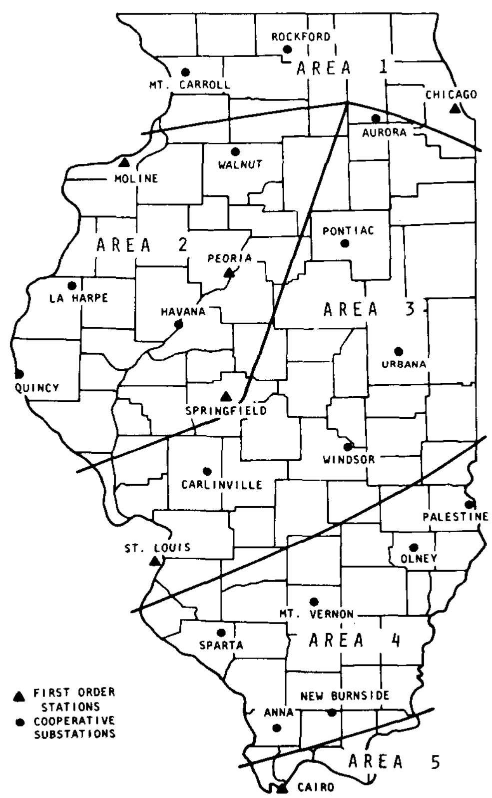


Figure 27. Data stations and areas of similar point snowfall frequencies

The distribution of maximum snowfall values for 7-day periods shown in table 25 indicates that the 2- and 5-year values of the five areas are considerably different, and

Table 24. Two-Day Maximum Snowfall Values for Selected Recurrence Intervals in Five Areas of Illinois

Area	Snowfall *(inches)* equalled or exceeded at given interval					
	2-yr	5-yr	10-yr	20-yr	30-yr	50-yr
1(North)	8.5	10.6	12.4	14.8	16.2	18.3
2(West)	7.4	8.6	9.8	11.2	12.0	13.4
3(SW-central)	7.0	8.6	10.2	12.1	13.4	15.2
4(South)	5.7	7.4	9.1	11.2	12.6	14.8
5(Extreme south)	4.2	5.8	7.5	9.7	11.3	13.5

Table 25. Seven-Day Maximum Snowfall Values for Selected Recurrence Intervals in Five Areas of Illinois

Area	Snowfall *(inches)* equalled or exceeded at given interval					
	2-yr	5-yr	10-yr	20-yr	30-yr	50-yr
1(North)	10.2	13.3	16.7	21.0	24.0	28.2
2(West)	8.2	10.8	13.2	16.3	18.2	21.5
3(SW-central)	7.6	10.1	12.8	16.3	18.7	22.0
4(South)	6.5	9.1	11.8	15.2	17.6	21.3
5(Extreme south)	4.6	7.0	9.4	12.7	15.3	18.9

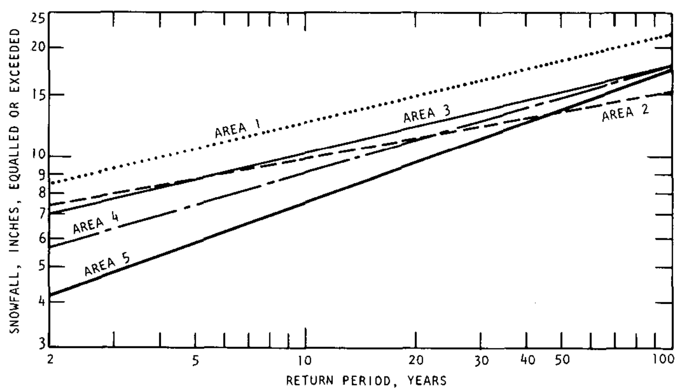


Figure 28. Area-mean recurrence interval curves for 2-day point snowfall values

that all values for area 1 (north) are greater than those in the other four areas. Areas 2, 3, and 4 have comparable values for the 20-year and longer recurrence intervals.

Record High 2-Day Snowfall Values

The record high 2-day snowfall values in the 1900-1960 period at 28 stations with 61-year records are shown in figure 29 along with their dates of occurrence. The highest value shown in the 61-year period was 26.0 inches at Quincy on 27-28 February 1900. The highest 2-day value at any Illinois station at any time in the 1900-1960 period was 37.8 inches at Astoria on 27-28 February 1900 (figure 21), but it was not plotted in figure 29 since the Astoria station was not one with a long-term operation.

Areas where relatively high maximums have occurred include northern, western, northeastern, and southeastern Illinois. Areas with relatively low (less than 14 inches) maximums include southwestern and west-central Illinois. The lowest maximum value was 11.8 inches at Moline.

The dates of maximum values shown for the 28 stations (figure 29) indicate that they occurred on 21 different dates, and only three 2-day periods produced a maximum at more than 1 station. These three dates were 27-28 February 1900 (maximum at 3 stations), 18-19 February 1908 (maximum at 3 stations), and 12-13 January 1927 (maximum at 4 stations). The occurrence of many different periods related to the 28 maximum values indicates that extremely heavy snowfall zones in Illinois are usually not widespread.

Nine of the 21 record snow periods occurred in February, six were in January, four in March, and two in December. Thirteen of the 21 periods came in the 1900-1918 period, and only eight record point snowfall periods occurred in the 42 years after 1918. The temporal distribution of severe winter storms (figure 3) did not indicate a high frequency of storms in the 1900-1918 period, but there were many more extremely damaging storms in the 1900-1920 period (table 12) than in any other 20-year period after 1920.

Maximum Point Snowfalls per Storm and Year

The maximum point snowfalls recorded in the 269 severe winter storms with amounts of 6 inches or more

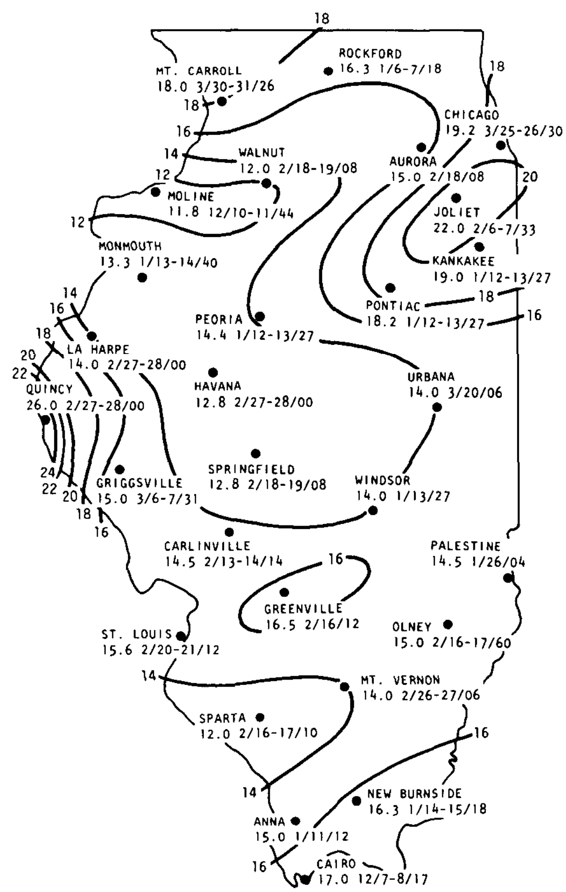


Figure 29. Maximum 2-day snowfall totals, in inches, and dates of occurrence in 1900-1960

Table 26. Maximum Point Snowfalls for Storms Producing 6 Inches or More

Snowfall (inches)	Oct-Nov	Dec	Jan	Feb	Mar	Apr-May	Total
	Number of storms						
6.0–8.0	8	21	25	22	17	7	100
8.1–10.0	4	15	15	15	13	1	63
10.1–12.0	3	10	14	7	8	1	43
12.1–14.0	1	4	7	8	8	4	32
14.1–16.0	1	4	3	3	3	1	15
16.1–18.0	0	1	1	3	2	0	7
18.1–20.0	0	0	4	0	2	0	6
20.1–22.0	0	0	1	1	0	0	2
22.1–24.0	0	0	0	0	0	0	0
> 24.1	0	0	0	1	0	0	1
Totals	17	55	70	60	53	14	269

were sorted as shown in table 26. There were 31 storms (upper 12 percent) with point values of 14.1 inches or more. Most of these heavy values came with storms in January, February, and March. Five of the nine storms with the heaviest point amounts occurred in January, further indicating the greater likelihood for heavy snow in midwinter.

The highest 2-day point value anywhere in Illinois in each year during the 1900-1960 period is shown in table 27. A value of 10 inches or more occurred in 52 of the 61 years. In 21 years the annual high was somewhere in the northwest section, and in 14 years it was in the north-east. The annual high occurred only once in the central and east-southeast districts.

Maximum Snow Depth

The snow depth (snow on the ground) data at the 28 stations (figure 29) with long records were analyzed to determine the maximum depth recorded on any day in the 1900-1960 period. Isodepth lines based on these record values were drawn to derive a statewide pattern (figure 30). This pattern shows that the lowest maximum depths, less than 15 inches, have occurred in a corridor across southern Illinois and in a small area in west-central Illinois. Values in excess of 25 inches have occurred in all of northern Illinois and in isolated areas in western and eastern Illinois.

Assuming a 10:1 ratio of snow to water,[24] the 15-inch maximum depths represent a weight of 7 pounds per square foot and the 35-inch depths in extreme northern Illinois are equal to a load of 18 pounds per square foot.

Maximum Glaze Accumulations

Because of the size, shape, and open exposure of most communication and power service wires, they have a greater collection efficiency and normally acquire thick-nesses of glaze equal to or greater than that on most other exterior objects. Bennett[7] reported that ice thickness on highways is as great as that on wires about 80 percent of the time. Therefore, many measurements of glaze in the various severe storms in Illinois have referred to the radial thickness of ice on wires or to the weight of ice on wires. In some instances, the relative difference between the weight of tree branches and that of the ice they have collected has been noted, since tree damage is a major factor in glaze storm damages.

Table 27. Annual Maximum 2-Day Point Snowfall Values in Illinois

Year	Date	Snowfall (inches)	Location	State section
1900	27-28 Feb	37.8	Astoria	W
1901	2-3 Feb	14.0	Wheaton	NE
1902	15 Dec	8.0	Astoria	W
1903	12-13 Dec	13.5	Chicago Heights	NE
1904	25-26 Jan	15.0	Albion	SE
1905	7-8 Feb	11.2	Dixon	NW
1906	26-27 Feb	14.0	Mt. Vernon	SE
1907	15-16 Jan	10.5	Monmouth	W
1908	18-19 Feb	18.0	Astoria	W
1909	12 Dec	15.0	Freeport	NW
1910	16-17 Feb	18.0	Grafton	WSW
1911	5-6 Feb	14.3	Chicago	NE
1912	16 Feb	16.5	Greenville	WSW
1913	26-27 Feb	11.7	Galva	NW
1914	12-13 Feb	15.0	E. St. Louis	SW
1915	24-25 Dec	16.0	Quincy	W
1916	2-3 Mar	9.0	Grafton	WSW
1917	7-8 Dec	17.0	Cairo	SW
1918	6-7 Jan	19.0	Oregon	NW
1919	6 Dec	7.0	Freeport	NW
1920	5 Apr	12.0	La Harpe	W
1921	16 Apr	14.0	Freeport	NW
1922	18 Jan	6.3	Kankakee	E
1923	11-12 Mar	11.0	Freeport	NW
1924	20 Mar	12.0	Griggsville	WSW
1925	28-29 Oct	6.5	McLeansboro	SE
1926	30-31 Mar	19.0	Dixon	NW
1927	12-13 Jan	19.0	Kankakee	E
1928	17-18 Feb	13.0	Joliet	NE
1929	18-19 Dec	12.0	Danville	E
1930	25-26 Mar	19.0	Chicago	NE
1931	6-7 Mar	15.0	Griggsville	WSW
1932	20-21 Mar	14.0	Oregon & Sycamore	NW-NE
1933	6-7 Feb	22.0	Joliet	NE
1934	10 Dec	12.8	Chicago	NE
1935	22-23 Dec	9.0	Morrison	NW
1936	16-17 Jan	11.0	La Harpe	W
1937	13 Mar	11.5	Edwardsville	WSW
1938	7-8 Apr	15.7	Chicago	NE
1939	30 Jan	18.3	Chicago	NE
1940	13-14 Jan	13.3	Monmouth	W
1941	10-11 Mar	12.2	Freeport	NW
1942	5-6 Dec	11.1	Lincoln	C
1943	17-18 Jan	12.0	Rockford	NW
1944	10-11 Feb	12.5	Rockford	NW
1945	24-25 Dec	11.0	Dixon	NW
1946	8-9 Mar	9.5	Mt. Carroll	NW
1947	26-27 Mar	15.0	Harrisburg	SE
1948	1-2 Mar	13.8	Rockford	NW
1949	17-18 Jan	8.0	Dixon	NW
1950	7-8 Dec	15.2	Wheaton	NE
1951	20-21 Dec	19.0	Galena	NW
1952	2-3 Mar	13.0	Mt. Carroll	NW
1953	1-2 Mar	10.0	Charleston	ESE
1954	2-3 Mar	11.8	Chicago	NE
1955	21-22 Mar	9.0	Monmouth	W
1956	11-12 Feb	11.0	Park Forest	NE
1957	9-10 Jan	12.0	Sycamore	NE
1958	20-22 Jan	11.5	Dixon	NW
1959	20-22 Jan	21.6	Rushville	W
1960	9-10 Feb	15.1	Mt. Carroll	NW

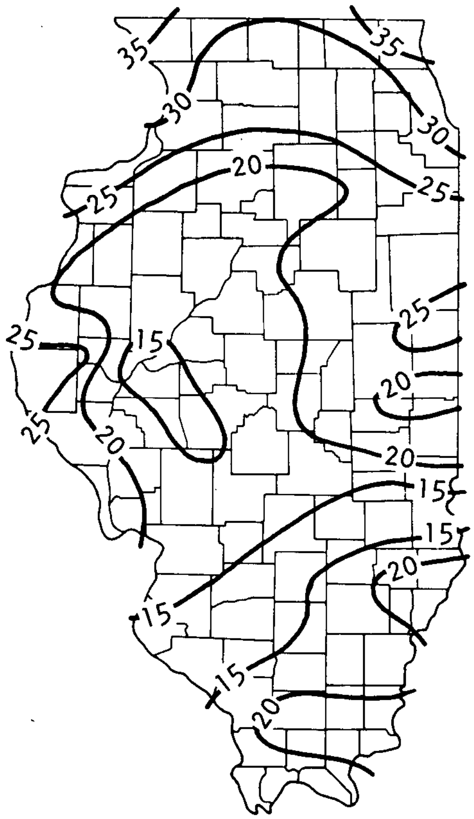


Figure 30. Maximum snow depth in inches, 1901-1960

Certain of these ice measurements recorded in some of the most severe Illinois glaze storms are listed in table 28. These do not represent all the extremes, but are those found in the records. However, they do serve as good approximations of the possible extremes. The listings of the large radial thicknesses show various locations throughout Illinois, indicating that severe glazing has occurred and can occur anywhere in Illinois.

In many of the severest glaze storms, the damage has resulted from a combination of excessive ice loads and subsequent high winds in the hours and days following the storm.[25] The winds furnish additional transverse loading, causing more breakage of the heavily glazed wires, poles, and trees. Much damage ensues when ice-covered tree branches fall on houses and wires.[7]

To obtain heavy glazing, it is necessary to have 1) continuous, relatively heavy precipitation which is supercooled by falling from a warm (above freezing) rain-generation layer of air through 3000 to 4000 feet of air with temperatures of 25 to 32 degrees F; and 2) moderately strong winds and cold surface objects that by evaporation and conduction can remove the latent heat of fusion (resulting when drops impact) to produce a high collection efficiency of the drops on surface objects.[7] The rate of accumulation of ice on an unheated object oriented normal to the wind is

$$I = V\ W\ 3600\ \ (10^{-4/2.54})\ (E/100)$$

where I is the icing rate in inches per hour, V is the wind speed in mph, W is the liquid water content in grams per cubic meter, and E is the collection efficiency.[6]

The Association of American Railroads made a 9-year national study of glaze accumulations on their communication wires.[25] These data were summarized by Bennett[7] according to the greatest point thickness measured in 60- by 60-mile squares, and these values are reproduced in figure 31. These data show that radial thick-

Table 28. Measures of Glazing in Various Severe Winter Storms

Storm date	Radial thickness of ice on wire *(inches)*	Ratio of ice weight to weight of 0.25-inch twig	Weight of ice *(oz)* on 1 ft of standard (#12) wire	City	State section
2-4 Feb 1883			11	Springfield	WSW
20 Mar 1912	0.5			Decatur	C
21 Feb 1913	2.0			La Salle	NE
11-12 Mar 1923	1.6		12	Marengo	NE
17-19 Dec 1924	1.2	15:1	8	Springfield	WSW
22-23 Jan 1927	1.1		2	Cairo	SE
31 Mar 1929	0.5			Moline	NW
7-8 Jan 1930	1.2			Carlinville	WSW
1-2 Mar 1932	0.5			Galena	NW
7-8 Jan 1937	1.5			Quincy	W
31 Dec 1947– 1 Jan 1948	1.0		72	Chicago	NE
10 Jan 1949	0.8			Macomb	W
8 Dec 1956	0.5			Alton	WSW
20-22 Jan 1959	0.7	12:1		Urbana	E
26-27 Jan 1967	1.7	17:1	40	Urbana	E

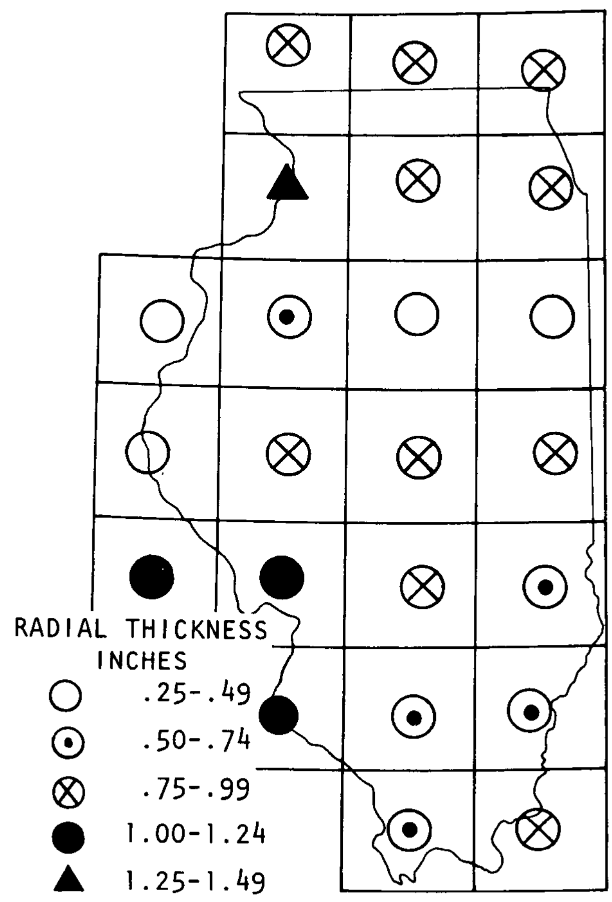


Figure 31. Greatest thickness of ice on wire in each square during 1929-1937

nesses of ice exceeding 0.25 inch occurred in all parts of Illinois during this 9-year period. They further reveal that points in the south-central and northern portions of the state had maximum glaze thicknesses exceeding 0.75 inch, although the area1 variations shown in figure 31 may largely be due to the short sampling period.

Until more precise data are collected, it is believed that the point design values for extreme glazing are equivalent anywhere in Illinois. The best estimates for these extremes could be the highest values shown in table 28. Thus, wires anywhere in Illinois could experience glaze with a radial thickness of 2 inches and a weight of 72 ounces per foot. However, Seeley[26] reported that the glaze weight on wires from a I922 storm in Michigan exceeded 176 ounces per foot, and that the ratio of ice weight to twig weight was 32:1. Root[27] reported a ratio of 15:1 at Springfield in 1924, and 17:1 was measured in the center of the 1967 glaze storm (table 28). Tree damage from glaze increases with tree size, and the weight of ice on a 50-foot high evergreen tree has been estimated to be 50 tons.[7]

Glaze-Wind Relationships

Strong winds both while glaze is occurring and after a storm greatly increase the amount of tree and wire damage. Bennett[7] has found that tree damage from glaze is usually minor unless accompanied by strong winds. The joint effect of ice and wind on wires greatly increases the transverse loading (for wires normal to the wind), and also upsets wire equilibrium, producing erratic movements and breakage.

Wind data during and after severe glaze storms are often not collected because the glaze accumulation halts the mechanical operation of the wind measuring equipment. This situation occurred in the two severest glaze storms at Urbana (table 28).

The average hourly wind speeds measured during 542 hours when freezing rain or drizzle were occurring at Urbana were calculated from all available data from the 1952-1967 period. These data showed that during 5 percent of the time (hours) wind speeds were under 5 mph; in 19 percent of the time speeds were 6-10 mph; in 51 percent, 11-15 mph; in 21 percent, 16-20 mph; and in 4 percent 21-35 mph.

Winds after a severe glaze storm has ended, and when accumulations are at a maximum, are equal or greater in importance for damage production than winds during the storm. In studying wind effects on glaze-loaded wires, the Association of American Railroads[25] concluded that maximum wind gusts were not as significant (harmful) a measure of wind damage potential as were the speeds sustained over 5-minute periods. In table 29, the maximum 5-minute wind speeds measured in the after-storm periods of 148 glaze storms throughout the country during 1926-1937 are summarized for 5-mph intervals.[7] The average of these 5-minute maximums was 17.5 mph, and 33 percent of the occurrences (cases) had speeds of 20 mph or greater. Shown with each interval in table 29 is the number of times the glaze accumulation on wires had a radial thickness of 0.25 inch or more. Twenty-seven of the 32 cases with 0.25-inch or thicker glaze were with a 5-minute wind of 15 mph or faster. The average velocity of the 32 cases was 20 mph.

Table 29. Summary of Maximum 5-Minute Wind Speeds Occurring after 148 Glaze Storms

Wind speed intervals (*mph*)	Number of cases	Number of cases when radial thickness of ice was 0.25-inch or more
0–4	1	0
5–9	17	2
10–14	35	3
15–19	46	15
20–24	27	6
25–29	10	3
30–34	6	1
35–39	2	1
40–44	1	0
45–49	2	1
50–54	1	0
Total	148	32

Table 30. Wind-Glaze Thickness Relations for Five Periods of Greatest Speed and Greatest Thickness

	Five periods when five fastest 5-minute speeds were registered		Five periods when five greatest ice thicknesses were measured	
Rank	Speed (*mph*)	Ice thickness (*inches*)	Ice thickness (*inches*)	Speed (*mph*)
1	50	0.19	2.87	30
2	46	0.79	1.71	18
3	45	0.26	1.50	21
4	40	0.30	1.10	28
5	35	0.78	1.00	18

Specific glaze thickness data for the five fastest 5-minute speeds, and the speeds with the five greatest measured glaze thicknesses, are shown in table 30. Although these extremes were collected from various locations throughout the United States in an 11-year study period, they are considered applicable design values for any location in Illinois. In a few unusual glaze storms (figure 20), the high wind speeds with glaze came from associated thunderstorms.[20] Although the amount of wind data with and after glaze storms is small, the available data suggest that moderate speeds are most prevalent. Speeds of 25 mph or higher are not unusual, and there have been 5-minute winds in excess of 40 mph with glaze thicknesses of 0.5 inch or more.

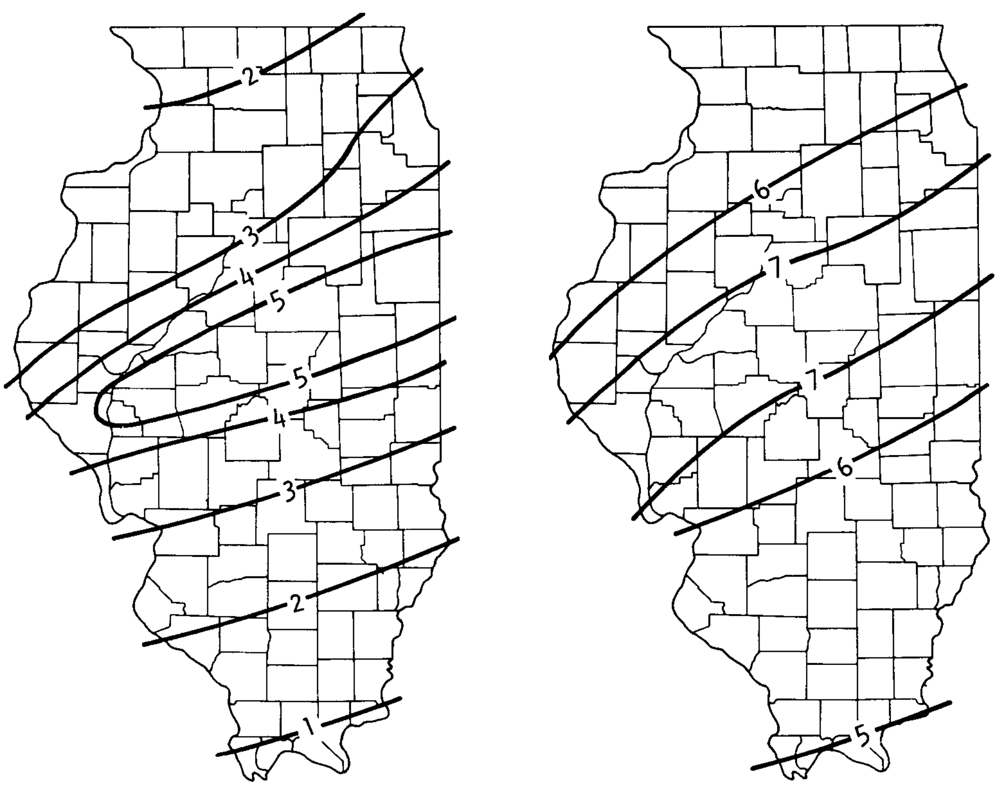
Average Frequency of Days with Heavy Snow, Glaze, and Sleet

A part of the design problem for severe winter storms concerns the point frequencies of days with the various conditions associated with these storms. Not all days with glaze or sleet at a point are associated with severe storms,

a. Annual number of days with 1 inch or more of snowfall

b. Number of 2-day periods with snowfall of 4 inches or more in an average lo-year period

c. Annual number of days with 3 inches or more of snow on the ground



d. Annual number of days with glaze

e. Annual number of days with sleet

Figure 32. Average patterns of days with snowfall, snow depth, glaze, and sleet, based on point data

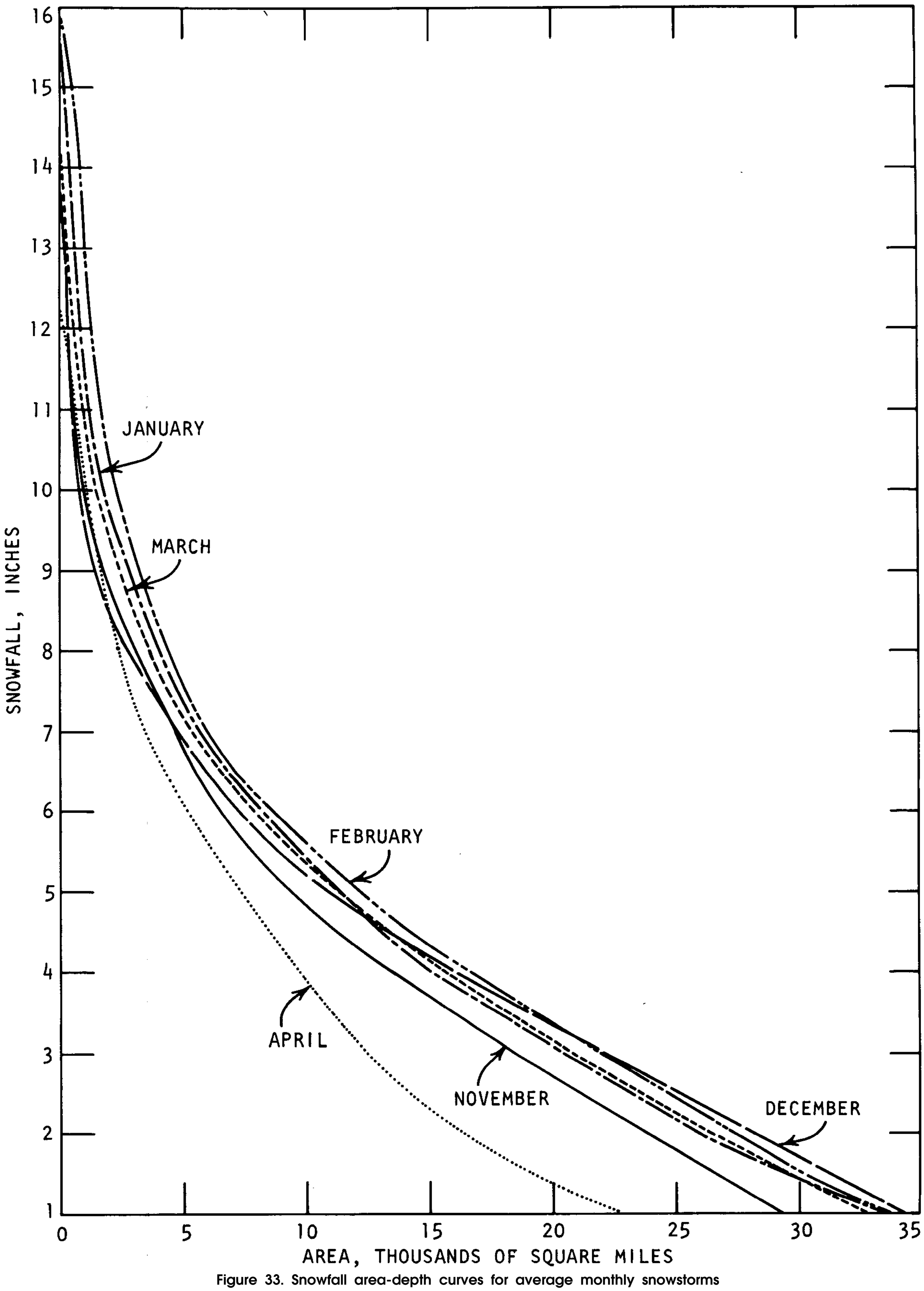


Figure 33. Snowfall area-depth curves for average monthly snowstorms

but many are. Sixty-two Illinois stations[5] with weather records for the 1901-1962 period were analyzed to determine point averages for the number of days with 1) l-inch or heavier snowfalls, 2) 3-inch or deeper depths of snow on the ground, 3) glaze, and 4) sleet. The number of 2-day periods with 4 inches or more snowfall also was calculated from these records, and the resulting average patterns for all five conditions are shown in figure 32.

The distribution of heavy snowfall days and deep snow-depth days (figures 32a, b, c) all exhibit latitudinal distributions with points in northern Illinois experiencing more than three times as many days, on the average, as those in extreme southern Illinois. The highest point values occur in the extreme northwestern corner of the state. The glaze and sleet patterns (figures 32d and e) both have a maximum oriented WSW-ENE across central Illinois, and their lowest values in extreme southern Illinois.

AREAL DATA

Area-Depth Relations

A frequently used measure of the volume of precipitation over an area is the area-depth relationship. Curves based on these relations allow determination of the area covered by any volume of rain or snow.

Average monthly area-depth relations were developed for all winter storms (269 total) that produced 6 inches or more snowfall. The monthly area-depth curves in figure 33 reveal differences that can be related to calculations of average snow removal and water input by these severe storms. The average February storm covers considerably greater area with snow above 4 inches, whereas the typical December storm is the most widespread for depths of 1 to 4 inches. The average storm in April is least extensive at most depths. Area1 differences in depths less than 6 inches are considerable. The 6-inch depth in the average storm in February covers 8500 square miles; that in January is 8200 square miles; March, 8000; December, 7200; November, 6600; and that in April, only 5200 square miles. The shapes of the monthly average curves reveal the tendency for heavy snowfalls (8 inches or more) to be relatively small in area1 extent as compared with the extent of the area experiencing between 1 and 8 inches.

The most extensive snowstorms in each month, defined as those covering the greatest area of Illinois with 1 inch or more snowfall, were used to construct the area-depth curves in figure 34. The curve for the design storm on 27-28 February 1900 (figure 21) reveals very extensive coverage at all depths above 5 inches. The extensive storms in November, December, and January have area-depth relationships that are somewhat alike. The 11-12 January 1918 storm exceeded all other storms in area1 coverage in the 1- to 4-inch depths. Although the most widespread storms in March and April produced 1 inch or more snowfall over most of Illinois, these storms did not produce exceptionally heavy snowfall over wide areas.

The storm snowfall data for each of the three damage classes (minor, moderate, and extreme) were used to develop average area-depth relationships for each class (figure 35). The average curves show that at any depth,

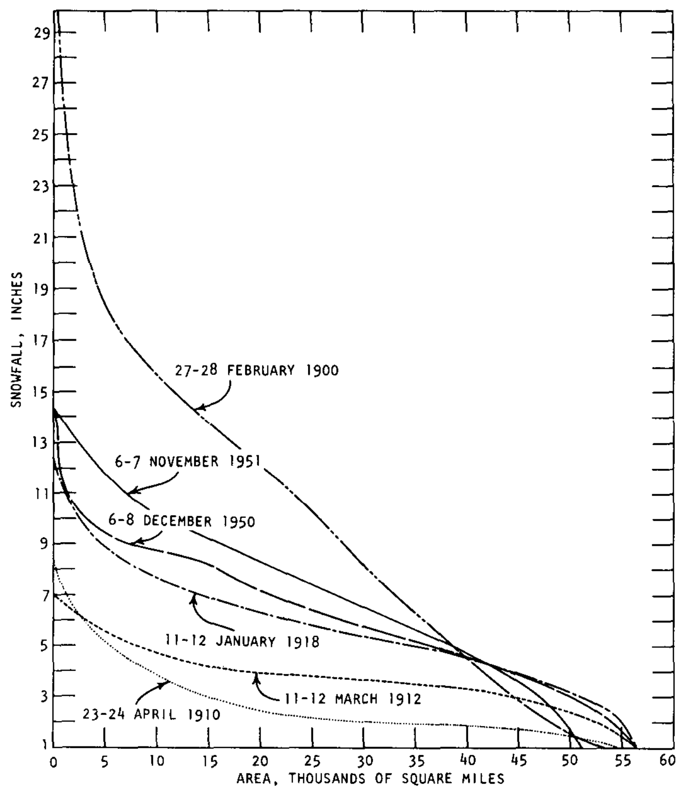


Figure 34. Snowfall Oreo-depth curves for most widespread storms in each month, 1900-1960

the area covered by a storm resulting in minor damage (less than $10,000) was considerably less than that with the more damaging storms. There was less difference between the curve for the moderately damaging storm and that of the extremely damaging storm, but at any given depth the extreme storm had slightly more area of snowfall. This suggests that the damage difference between these two classes was not a function of the total snowfall. The degree of damage for a storm was more likely a result of other factors, including the strength of the wind (drifting), the severity of the associated glaze, and the location of storm center (largely in rural or in urban areas).

Average area-depth relations were developed for the 6-inch or greater snowstorms in each of the five major

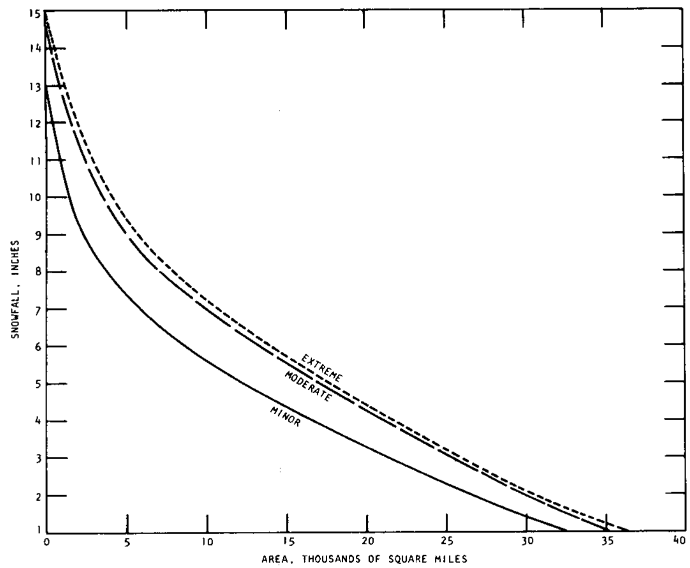


Figure 35. Average snowfall area-depth curves for different classes of damage

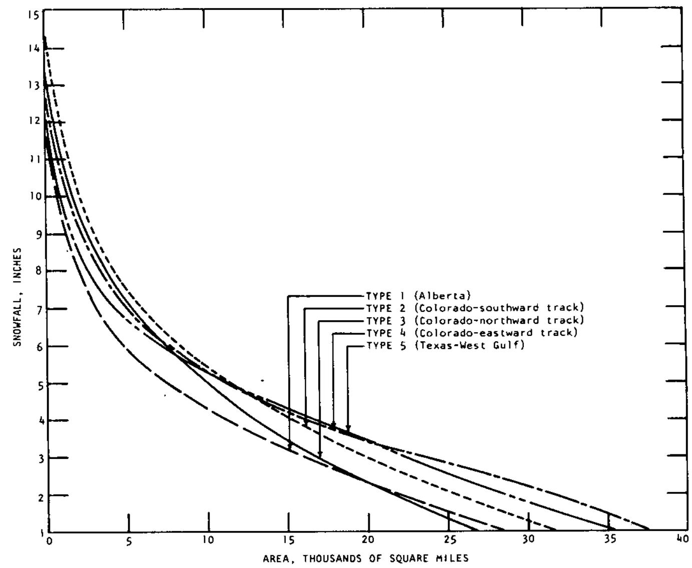


Figure 36. Average snowfall area-depth curves for different weather types

weather types. The average curves (figure 36) reveal that the average Alberta-derived storm (type 1) produces less extensive snowfall at most depths. The type 2 storm, which is the most prevalent type (table 16), has on the average the most extensive areas with snowfall exceeding 5 inches. At lower depths, 1 to 3 inches, the average type 4 storm has greater areal coverage.

The greatest difference in the area-depth curves of the five weather types is found in the values below 6 inches. There is little significant difference (less than 1000 square miles) in their area-depth values above 10 inches. The curves at the l-inch depth show that, on the average, the type 4 and 5 conditions produce the most widespread snowstorms in Illinois (35,000 to 37,500 square miles), whereas the type 1 and type 3 produce the least extensive storms (27,000 to 28,500 square miles). Interestingly, the most widespread storms (types 4 and 5) were quite infrequently related to the more damaging storms (table 18). These results further illustrate the relatively inexact relationship between the areal extent of snowfall and degree of storm damage.

Storm Model

Several average features of the 304 severe winter storms were utilized to develop a dimensional model of the storms. The average values of snowfall areas (table 6) from the 269 storms with 6 inches or more were used along with the 3:1 ratio of the median values for length and width of storm cores to develop the snowfall dimensions in the model (figure 37). The preferred orientation of all storm cores, 250 degrees, was used to orient the model, and other statistics relating to storm motion, duration, and initiation are shown.

The glaze storm data on areal extent (table 22) and orientation were also used in developing the storm model (figure 37). The glaze-snowstorms were analyzed to determine the average distance between the major axis of the glaze area and the southern boundary of the 6-inch snowfall area. As shown, the average distance was 50 miles. The length-width ratio of the glaze areas was calculated to be 4:1 and this was used with the average areal extent of glaze (8500 square miles) to derive an area 184 miles long by 46 miles wide.

Frequencies of stations reporting sleet in each winter storm were used to determine the average areal extent of sleet with the severe winter storms. The average extent was 11,800 square miles in a rectangular area, with a length 2.4 times its width. The sleet area usually was oriented with the glaze area, with its southern edge through the central portion of the glaze area (figure 37).

The pattern shown in figure 37 is considered to model the sizes and areal relationships of the basic features of a severe winter storm in Illinois. The synoptic weather condition most likely to produce this storm is a low developing in Colorado that initially moves southeastward but then northeastward up the Ohio River Valley. However, only 10 percent of the lows that develop in Colorado during the cold season produce a severe storm in Illinois. The southern edge of the 4-inch snowfall area (figure 37) is usually 50 to 75 miles north of the attendant surface low.[28]

Regional Probabilities of Severe Storm Centers

The frequency of 6-inch snowfall cores expected during an average 10-year period is shown in figure 38a for the nine districts of Illinois. Both northern districts can ex-

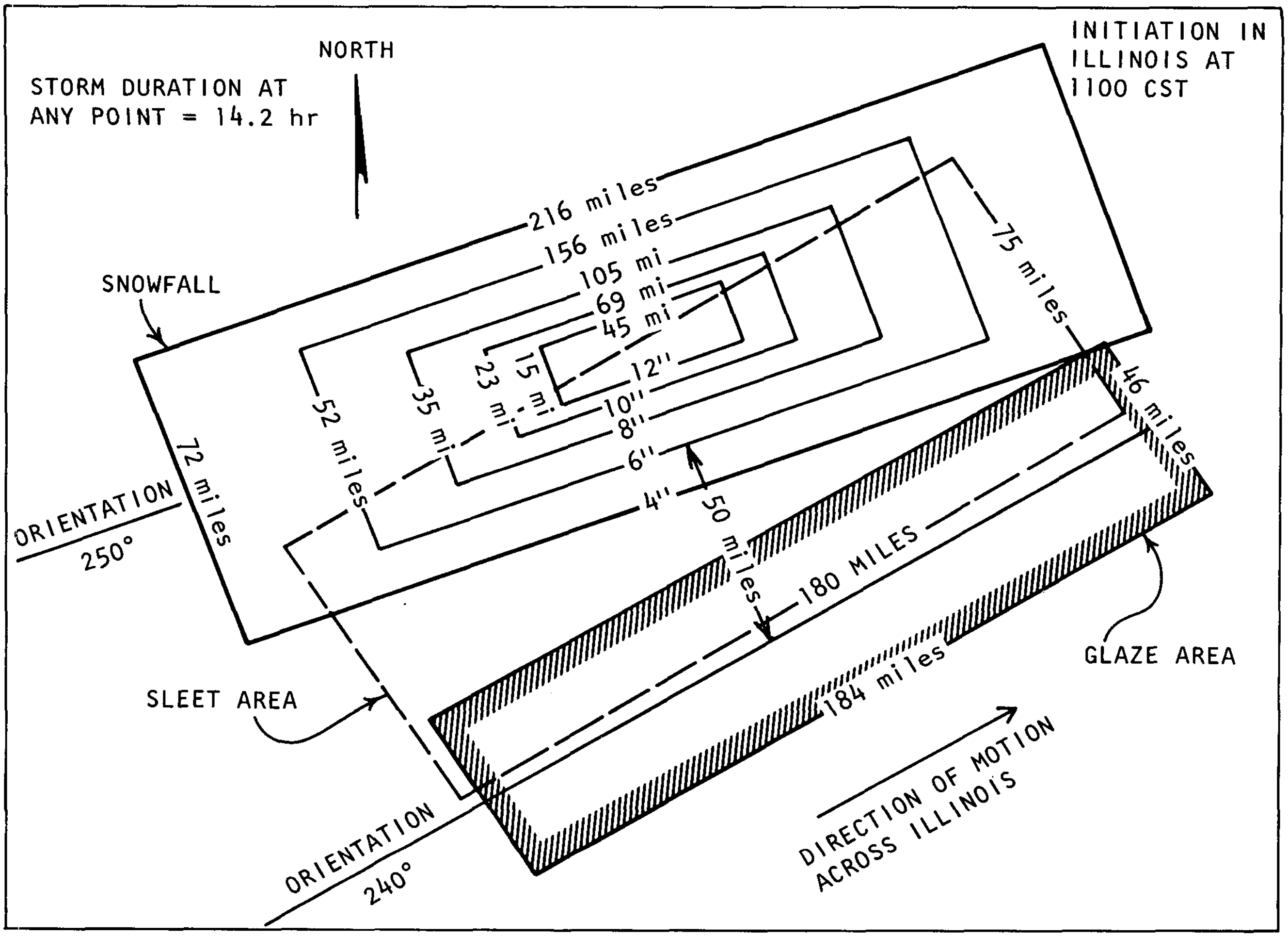


Figure 37. Model of severe winter storm in Illinois

pect two to three such storm cores in a year, whereas each of the two southernmost districts can expect only one a year.

The frequency of damaging glaze areas in three state regions (figure 38b) during an average 10-year period reveals a greater likelihood of their occurrence in central Illinois. A 23-year study of ice on telephone wires[7] provided data for portrayal of areal frequencies of storms producing thick (0.75-inch) glaze on wires (figure 38c). This pattern shows that most of Illinois has an equal likelihood for one glaze storm of this severity at least once every three years. Only in extreme southern Illinois is the heavy glaze storm likelihood considerably less.

Regional Probabilities for Successive Storms

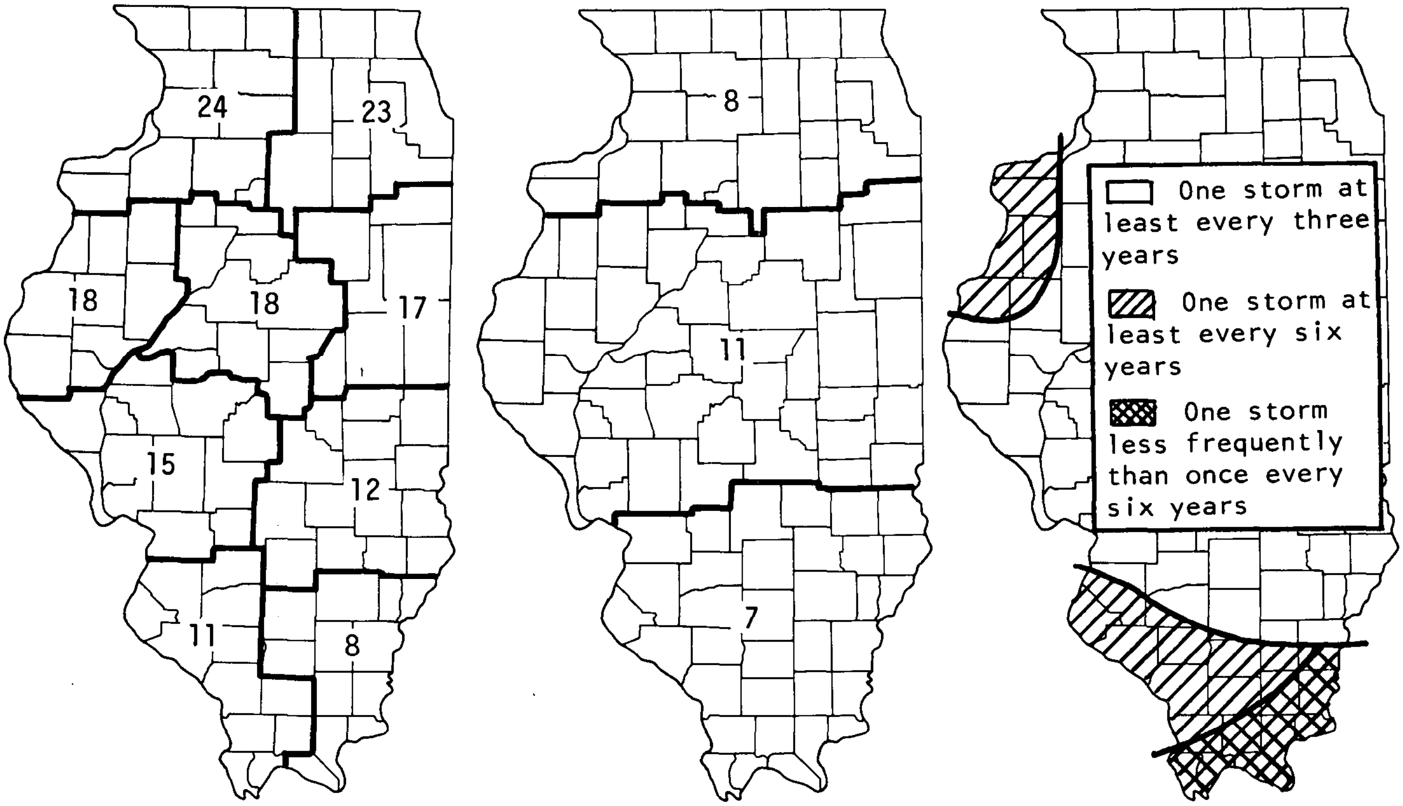
The chance for a 6-inch snowfall core to occur in an area after one has just occurred was determined for varying periods of time up to 30 days. Probabilities developed for each of the nine state districts (table 31) show considerable areal variations. For instance, probabilities for a second storm within 20 days in the WSW and SE districts are nearly 30 percent, whereas the probability in the W district is only 12 percent. For all time periods, chances for a following storm (core) are greatest in the WSW, SW, SE, and NE districts. Chances for successive storm cores are poorest in the W and C districts.

Persistence of Severe Snow and Glaze Conditions in Storm Centers

The length of time (days) after a storm ended until the heavy snow in the storm cores began melting and was

Table 31. Probability That a 6-Inch Storm Core Will Occur in a District after One Has Ended

Time of occurrence of second storm after end of first storm	Probability *(percent)* in each district								
	NW	NE	W	C	E	WSW	ESE	SW	SE
Within 5 days	6	9	1	6	6	13	7	9	14
Within 10 days	10	15	7	13	11	19	14	17	22
Within 15 days	15	19	10	15	14	24	15	18	26
Within 20 days	17	22	12	16	18	28	17	20	28
Within 25 days	19	25	13	17	20	29	18	25	32
Within 30 days	20	27	14	18	22	30	18	26	32



a. Number of 6-inch snowfall cores in an average 10-year period

b. Number of damaging glaze areas expected in an average 10-year period

c. Areal frequencies of storms with 0.75-inch or thicker ice on wires

Figure 38. Regional frequencies of severe storm centers

not a local problem could be determined for 192 of the 269 storms with 6-inch or greater snowfalls. The distribution of lengths (table 32) reveals that snowfall persistence in all months except January was usually less than 3 days. Persistence seldom exceeded 15 days for storms in most months, and the longest value was 32 days. The average values (table 32) vary from less than 1 day (April) to 5 days for January storms.

A similar analysis for the 92 glaze storms was based on the persistence of glaze in the center (worst) of the

Table 32. Persistence of Deep Snow in Storm Cores after Storm Ends

Persistence *(days)*	Number of storms Nov	Dec	Jan	Feb	Mar	Apr
1-3	12	23	21	28	29	4
A-7	1	10	13	7	1	0
8-15	1	8	9	6	2	0
≥ 16	0	1	8	6	2	0
Average length *(days)*	2	3	5	4	2	<1
Maximum length *(days)*	9	20	32	28	20	1

glaze area. In 66 storms (72 percent), the heaviest glaze layers disappeared within 2 days; in 11 storms, in 3 to 5 days; in 8 storms, in 6 to 8 days; in 4 storms, in 9 to 11 days; and in 3 storms, from 12 to 15 days. Fifteen days was the maximum persistence of glaze in any storm center. The average glaze persistence in each month was less than 2 days.

Average persistence values were calculated for the center (worst) part of the minor damage storms, the center of the moderately damaging storms, and the center of the extremely damaging storms. The average value for the minor storms was 5 days, that for the moderately damaging class ($10,000-$200,000) was 8 days, and that for the extremely damaging class was 10 days.

Persistence values for the five weather types also were analyzed. The average values for type 1 (Alberta), type 4 (Colorado-east track), and type 5 (Texas-West Gulf) were 2 to 3 days. The average value for type 2 (Colorado-south track) was 6 days, and that for type 3 (Colorado-north track) was 5 days. This indicates that, on the average, storms of types 2 and 3 are followed by colder air than are storms of the other types.

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