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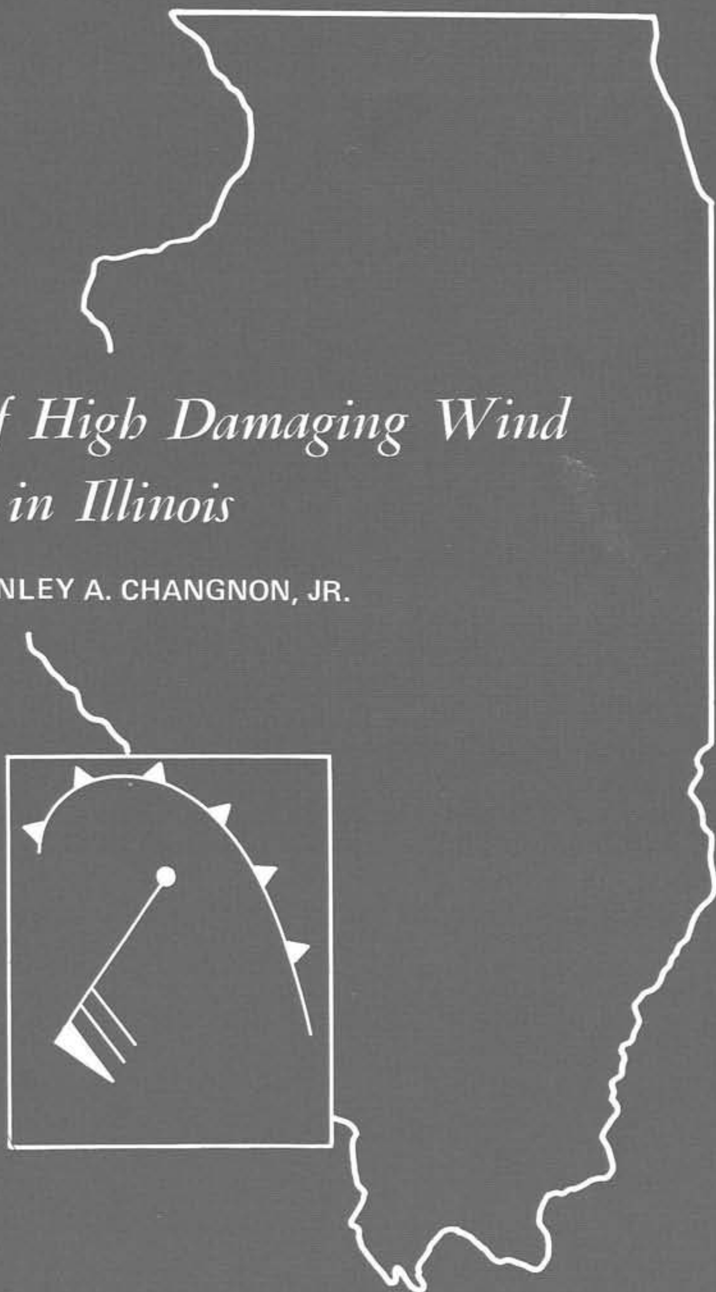

Climatology of High Damaging Wind in Illinois

by STANLEY A. CHANGNON, JR.

ILLINOIS STATE WATER SURVEY
URBANA
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REPORT OF INVESTIGATION 95

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Indexing Terms: Crop losses, mesoscale meteorology, severe storms, straight line winds, structural design, weather losses, wind climatology, wind energy.

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ABSTRACT

High winds (in excess of 40 mph) of a non-tornadic origin are a major weather hazard in Illinois, producing more property loss than any other weather hazard and the third greatest weather loss to crops, in all 23% of total property/crop losses due to severe weather. They cause an average of one death per year. High winds data are also important in structural design and wind energy considerations. Although there is a lack of definitive data, historical data from 43 cooperative substations and 6 first order stations, plus recent wind sensor data from two (short-period) dense networks and a10-year sample of recorded wind speed data at one location, were used to develop basic climatological information on high winds in Illinois. The study treats spatial and temporal variations in both averages and extremes to dimensionalize the incidence of days with high winds.

Damaging straight line winds peak in the spring and are least frequent in early fall. Summer thunderstorms are the major producers of high winds, but in all other seasons deep low center passages are the major cause. High winds are most frequent in southern Illinois, but more of the extreme events (in excess of 90 mph) occur in northern Illinois. The state has an average of 67 days of high winds a year. Outbreaks tend to cover from 300 to 6000 square miles and are more extensive during the colder half year. High wind events in summer are short-lived, typically less than 5 minutes, but in other seasons last longer having spans of 2 to 4 hours with intermittent gusts.

INTRODUCTION

One of the major severe weather hazards of the continental climate of the central United States is the high, damage-producing winds associated with deep cyclonic storms and/or thunderstorm activity. These winds are unrelated to tornadoes, and in Illinois they produce greater damage to crops and property than do tornadoes (Changnon, 1972).

Prior Illinois climatological studies have treated other severe storm phenomena including thunderstorms (Changnon, 1957), hail (Huff and Changnon, 1959), lightning (Changnon, 1964), tornadoes (Wilson and Changnon, 1971), and heavy rainstorms (Huff et al., 1958). The only remaining unstudied severe weather phenomenon is the damaging high winds of non-tornadic origin.

The climatological study of these winds was rooted in the premise that data on damage production by these winds and wind speed data recorded at the few Illinois first order stations were insufficient to define the time and space variations of these winds. Hence, historical data from the cooperative substations within Illinois were utilized extensively to obtain the areal detail desired for frequencies of days with "high winds."

Fortunately, since about 1900 the cooperative observers at all Illinois substations were asked to record, on a daily basis, the occurrence of high winds. High winds were actually defined as "damaging" in the sense that such winds were recorded when damage was produced to vegetation, buildings, or other property (U.S. Department of Commerce, 1962). This is, at best, a qualitative "yes or no" evaluation, although the U.S. Weather Bureau has found that wind speeds in excess of 47 mph produce damage to property, and winds in excess of 39 mph or higher often produce crop damage. The cooperative observer records at Urbana, where "high winds" were listed on the basis of local damage, were compared with continuously recorded wind speeds at Urbana. This indicated that in 90% of the instances when the observer had reported high winds and damage in the local area to trees and/or structures, local wind gusts exceeded 45 mph. A few damages occurred with winds in the 40 to 45 mph class.

Basically this study focused on the incidence of days with high damaging winds — generally, winds with speeds in excess of 45 mph. No extensive effort to quantify the loss against speed was made; these are simply yes or no daily occurrences. The study treats spatial and temporal variations in both averages and extremes in an attempt to dimensionalize the incidence of days with high winds. Daily frequencies of wind speeds in various speed classes were analyzed for six first order stations.

As will be shown in the results, days with high winds have occurred in all months in all parts of Illinois. They are generally most frequent in the late winter, spring (March-May), and early summer, and least frequent in late summer and early fall. In general, these non-tornadic, yet damaging high winds are produced largely by one of two conditions. The condition that is most prevalent in the winter and early spring events is the deep cyclonic storm of broad areal dimensions, frequently with strong winds persisting for several hours over large parts of Illinois. The other major producer of high winds is the thunderstorm, mainly in the spring and summer. The strong downdrafts of large thunderstorms, typically in well-organized lines of storms such as squall lines, produce outbreaks of strong surface gusts ("straight line winds") that usually last only a few minutes at a point, but can cause considerable damage.

The incidence of damaging winds on a mesometeorological scale has been inadequately studied, not because of a lack of interest but primarily because of the lack of adequate recording wind networks, both in areal extent and density of instruments. A few good dense networks have been operated but often for short periods. This study of "days with" data from cooperative substations, although largely based on some 50 stations scattered throughout Illinois (~1 per 1000 square miles), is certainly not adequate to define the exact spatial dimensions of high wind areas. This is particularly true of their space relationships with the phenomena producing them, and particularly thunderstorms. That type of wind data just does not exist on a continuous-sampling, long-term basis. However, study of the substation data helps reveal the existence and utility of "days with" data of the cooperative substations (Changnon, 1962).

Acknowledgments

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IMPORTANCE OF HIGH WIND INFORMATION

The major rationale for this investigation was the need to provide information describing one of the major damage-producing weather phenomena in Illinois, and for that matter of the United States. This study of the climatology of high winds in Illinois was pursued to furnish basic climatological information desired for a variety of scientific and business interests.

First, let us consider property losses because wind damages to property are much greater than wind damages to crops, at least in amonetary sense. Changnon et al. (1977) presented information on wind-produced losses to property in the United States over the 1948-1975 period.

As shown in table 1, non-tornadic wind storms of the cyclonic variety produced 13% of all the

Table 1. U.S. Losses to Winds in 1948-1975

	Average loss (1975 dollars)	*Portion of all national property losses due to severe weather*
Wind storms not associated with thunderstorms, tornadoes, hurricanes, or tropical storms	$43.7 million	13%
Thunderstorm-produced straight line winds	$28.8 million	8%
Total	$72.5 million	21%

property losses due to severe weather. It should be noted that this value was derived from a study of 411 weather catastrophes in the United States with catastrophe defined as an event producing at least $1 million in loss. Freidman (1976) further estimated that weather losses due to non-catastrophes were approximately equal to the catastrophic losses shown in table 1. Hence, all the dollar values in table 1 could essentially be doubled to get a national annual average property loss value due to non-tornadic, non-tropical (storm) winds. That is, the total of $72.5 million shown in table 1 based on catastropic events would be doubled, or approximately $150 million (in 1975 dollars) would represent the national loss in property due to "high winds." Importantly, as shown in table 1, these winds produced 21% of the national total property loss due to severe weather. In comparison, tornadoes produced 26%, hail 12%, and tropical storms 41%. Clearly, the high damaging winds of non-tornadic and non-tropical storm origin are a major national problem.

Changnon (1972) reported on an extensive study of severe storm-produced losses in Illinois during 1950-1957, with losses both to property and to crops. The values for high damaging wind showed an annual average loss (in 1957 dollars) of $3.352 million to property in Illinois. That 8-year average was higher than the property losses produced by any other weather peril, and it easily exceeded the annual average tornado-produced property losses in Illinois. The crop losses produced by winds had an annual average loss of $386,000, ranking as the third highest values of all the severe storm perils (following hail and rain losses). The total average annual value of high wind losses in Illinois was $3,738 million, ranking as the third highest total behind hail and heavy rains losses. Deaths related to straight line winds averaged 1 person per year. Importantly, straight line winds caused 23% of all the severe weather losses to property in Illinois. This compares favorably with the value of 21% for the United States (see table 1).

Crop-related wind damages in Illinois frequently are interrelated with the occurrence of hail. Changnon (1967b) in a study of crop hail losses in Illinois found the following relationships for the occurrence of damaging winds with crop hail damage. First, 100% of the "much damage" hail occurrences, those with greater than 50% crop losses, came with observer reports of "damaging winds." Second, 95% of the crop hail damages in the 5 to 50% range also had reports of damaging winds. Third, only 13% of the hail reports with no crop-hail damage were listed as having "damaging winds." The occurrence of small or large, many or few hailstones *without* the simultaneous occurrence of high winds does not produce much damage to crops in Illinois. Hail damage is very dependent upon the simultaneous existence of strong winds to drive hailstones at nonvertical angles. Changnon (1967b) also studied the peak gusts that occurred with hailfalls at Urbana over a 20-year period. The average peak gust values with hail in the spring season (March-May) ranged from 24 to 29 mph, those with summer hailfalls averaged 27 mph, and those with fall season hailfalls averaged 31 mph. In general, hail damage to local crops did not occur until peak gusts reached or exceeded 35 mph.

Another Illinois study (Changnon, 1971) dealing with the relationship between hailfall characteristics and crop damage was based on hail sensors. It found that the degree of corn and soybean damage was well related to the impact energy, or force of the impact of hailstones. Impact energy is increased by high winds that drive the hailstones at a speed faster than their terminal velocity.

Some quantitative wind and hailfall results (Changnon, 1973; Morgan and Towery, 1975) were obtained from data based on multi-sited hail sensors. These data revealed that windblown hail occurred in 60% of all hailfalls. Results also demonstrated that the total hail impact energy imparted by windblown hailstones can easily be five times as great as that in the absence of wind (Morgan and Towery, 1975). A further study (Towery et al., 1976) of hail losses in the lee of buildings and rows of trees revealed that hail losses were 3 to 12 times less in areas where crops were shielded from the wind by large obstacles than in adjacent areas where they were unshielded. The area of reduced loss generally extended horizontally 10 times the height of the obstruction.

Another assessment of wind-produced damage to crops was presented by Changnon (1972). The average crop yield losses due to various severe weather conditions, including drought and very high and low temperatures, were assessed for the Corn Belt. Generally, the average wind-induced loss to corn yields was 3.8 bushels per acre, ranking as the third highest damage producer to corn behind drought and excessive moisture. The wind-produced losses to soybeans averaged 1.0 bushel per acre, ranking as the fourth highest damage among the 10 weather factors producing losses to soybeans.

Awareness of the magnitude of losses by high winds of non-tornadic origin has grown in recent years. Several commercial aircraft-accidents have occurred since 1970, primarily during landings of jet liners at major airports in the Midwest and East Coast. Many of these have been associated with surface or near surface gusts generated by thunderstorms occurring as aircraft were in a low-power position prior to landing. Fujita (1978) has further expounded on these critical winds and has labeled a certain class of them as "downbursts." Concern over these strong winds generated by thunderstorm activity in the Midwest helped lead to an intensive field study of these downburst phenomena in the Chicago region in 1978 as project NIMROD (Changnon and Semonin, 1977).

The advent of large meteorological field projects in Oklahoma and in Illinois during 1978-1979 have provided detailed wind data for studies of the surface dimensions of these phenomenon and their causes. The 1979 data from central Illinois have been used herein to obtain detailed strong gust information.

In general, more information on the frequency, both in time and space, and damages of non-tornadic straight line winds in Illinois will prove useful in a variety of other future design and operational systems. Among these are concerns over wind energy systems that might be damaged by high winds, transmission lines that can be damaged, and all other forms of property. The risks to new structures need continuing reassessment for rating problems of the insurance industry.

DATA AND ANALYSIS

This climatological study was largely based on the instances of days with high winds (or damaging winds) as recorded at some 50 cooperative substations scattered throughout Illinois. These substation data were carefully reviewed and edited by Water Survey climatologists prior to their entry on IBM punch cards in the 1950s. Hence, a data period carefully screened by Survey scientists was that for the 1901-1948 period. It was considered to have the best quality substation data within the 1901-1978 period. Since 1948, data from the cooperative substations have not been screened as carefully by the Weather Service, and cooperative substation data have decreased in quality considerably over the last 20 years.

The desired utilization of the cooperative substation data in this climatological investigation required a careful evaluation of the data for 1901-1948 at each of the 50 stations. Cooperative observers may or may not enter and record the incidence of damaging winds, depending upon their interests and commitment to the task. Hence, the individual records of each of the stations were carefully examined by an evaluation methodology developed for hail and thunderstorm data at cooperative substations. The evaluation is essentially a "regional homogeneity" test, which consists of a series of comparisons of the monthly, 'seasonal, and annual values of a given station, and for a given period of years such as 1901-1948, with comparable values at surrounding stations (1901 vs 1901, 1902 vs 1902, etc.). Inspection of the monthly frequencies of high wind days for each of the years made it easy to identify and reject the poor record periods. Typically, a poor or uninterested observer would simply not record high wind events or one every few years.

The stations, their locations, and their periods of record identified as being of quality for high wind day observations are listed in table 2. The 43 substations had quality records of at least 15 years, and had more than 20 years, which usually identifies them with the term of an interested observer. In any given year in the 1901-1948 period, there typically were 35 to 40 substations with quality records. Also shown in table 2 are the annual average and 1-year maximum number of days with high winds, as developed from these records. The locations of these 43 stations plus those of 6 first order stations used in the study, are shown in figure 1. They provide a reasonably uniform density of observations across the state of Illinois.

Other data sources employed for certain parts of this study included the Urbana wind records for the 1948-1977 period. Urbana is one of the cooperative substations of the Weather Service and hence lists daily instances of high (damaging) winds. The Urbana station also has a fast response aerovane wind recording system that has operated during this 30-year period. These data allowed the

Table 2. Cooperative Substation Records of Days with High Winds in Illinois

Station	*Years of records*	*Total years*	*Annual average number of days*	*One-year maximum number of days*	*Station*	*Years of records*	*Total years*	*Annual average number of days*	*One-year maximum number of days*
Aledo	1901-48	48	4.1	18	McLeansboro	1907-48	42	3.2	15
Anna	1912-48	37	6.5	31	Minonk	1901-03,			
Bloomington	1901-48	48	3.4	19		1911-48	41	3.7	16
Charleston	1912-23,				Monmouth	1901-48	48	4.8	19
	1937-48	24	5.2	19	Morrison	1902-09,			
Carlinville	1910-48	39	4.3	20		1919-48	38	3.1	13
Danville	1901-48	48	3.9	22	Morrisonville	1901-48	48	4.3	24
Decatur	1901-26	26	4.2	10	Mt. Carmel	1901-15	15	2.8	16
Dixon	1901-09,				Mt. Vernon	1901-04,			
	1916-36	30	3.6	17		1923-44	26	2.7	18
Effingham	1901-24,				New Burnside	1901-48	48	6.2	31
	1943-48	30	3.6	21	Olney	1912-24,			
Flora	1901-36	36	2.9	19		1942-48	20	3.6	25
Freeport	1909-48	40	3.6	12	Palestine	1901-41	41	5.7	22
Galva	1902-09,				Pana	1901-14,			
	1931-48	26	4.1	11		1933-48	30	4.8	25
Harrisburg	1901-13,				Paris	1901-48	48	5.9	26
	1921-38,				Pontiac	1903-20,			
	1946-48	34	4.2	24		1926-48	41	3.7	21
Hillsboro	1901-21,				Roberts	1930-48	19	3.8	12
	1934-48	36	3.2	18	Rockford	1908-48	41	4.7	23
Hoopeston	1902-22,				Rushville	1901-48	48	5.2	27
	1929-48	41	2.7	22	Sparta	1901-48	48	3.3	19
Jacksonville	1901-41	41	4.2	18	Sycamore	1901-48	48	4.4	14
Joliet	1901-42	42	2.6	17	Urbana	1923-48	26	3.9	16
La Harpe	1901-48	48	3.2	16	Walnut	1901-48	48	3.9	18
Lincoln	1916-48	33	4.1	14	Waukegan	1924-48	25	4.0	27
Mascoutah	1907-38,				White Hall	1908-48	41	3.9	21
	1944-48	37	2.7	12	Windsor	1917-34	18	5.1	9

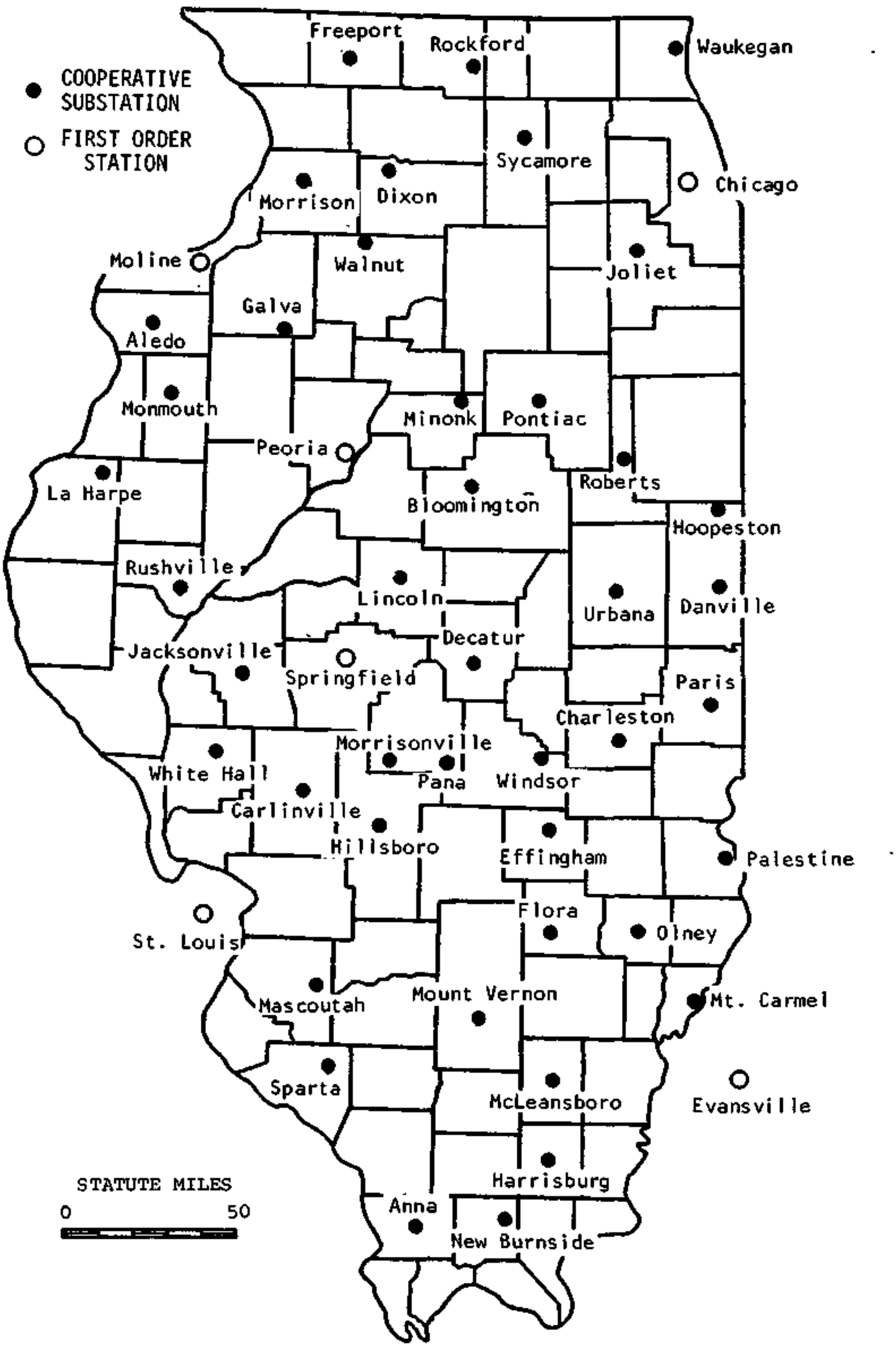

Figure 1. Locations of 43 substations and 6 first order stations used in the study

comparison of the already described high (damaging) wind days with wind speeds as recorded at Urbana. The recorded wind data at Urbana were also used to define the point duration of sustained high winds at different speeds.

The third data set utilized in portions of this study included that from first order stations operated by the National Weather Service in and around Illinois. First order stations are those manned 24-hours per day by trained observers and have continuous recording wind instrumentation. However, there are only four such stations with long historical wind records in Illinois (Chicago, Moline, Peoria, and Springfield) plus two other stations in adjacent states (St. Louis, Missouri, and Evansville, Indiana). Data from these six stations were used to determine the frequency of days with high wind speeds of varying magnitudes.

A fourth source of data was for the summer months only and from two weather networks with several wind sensors. One was an array of 6 stations in a 2000-square mile area around St. Louis which provided data for 1972-1975, and the other was a network of 27 stations in a 900-square-mile area with data for the summer of 1979. These two networks provided information on the areal extent, frequency, and duration of summer high wind events in small areas.

All the wind values are presented in miles per hour for a variety of reasons including that most envisioned users are familiar with wind speed in mph, as opposed to metric values. For convenience sake, the often referred to speed values and their metric equivalents are listed below.

miles per hour	*meters per second*
30	13.4
40	17.9
45	20.1
50	22.4
60	26.9

TEMPORAL DISTRIBUTIONS

Interannual Variations

The year-to-year fluctuations in high wind day frequencies in Illinois were examined, along with the temporal differences during the 1901-1948 period. The annual number of days with high winds in Illinois during 1901-1948 is shown in figure 2. A flat trend is not apparent. Values were relatively high in the 1904-1913 period and 1942-1948 period, both of which were also abnormally wet periods in Illinois (indicating more storminess) with a low reached in the 1920s.

Since quality data sources fluctuated with time and could influence the state frequency of high winds, the number of cooperative substations with quality high wind frequencies were also plotted on figure 2. The number of quality stations remained between 30 and 35 per year during most of the 1908-1948 period, and sampling is likely not a factor in the temporal variations shown for this period. However, the lower number of stations in 1901-1907 potentially affects (lowers) the frequency of high wind days in the 1901-1907 period.

The high values in the 1940s were found in all seasons. Table 3 presents the seasonal and annual averages of high wind days for decadal periods (except the 8-year period of 1941-1948). The 1920s also had the lowest frequency in all seasons.

The year-to-year differences in the annual number of high wind days within Illinois were determined. The largest change was 49 days (1941 to 1942) and the lowest was 0; the average year-to-year difference was 12; the greatest interannual variations occurred in the 1934-1948 period when the average was 20.

Monthly Frequencies

Since the incidence of days with high (damaging) winds is low at most points, averaging between 2 and 5 days per year (as shown in table 2), an analysis based on monthly frequencies was not pursued, and much of the temporal analyses focused on time and space variations of seasonal and annual values. However, the monthly totals at the cooperative substations were used to investigate the relative magnitudes and ranks of the monthly occurrences. The monthly values at each station were ranked according to their top five values, then plot-

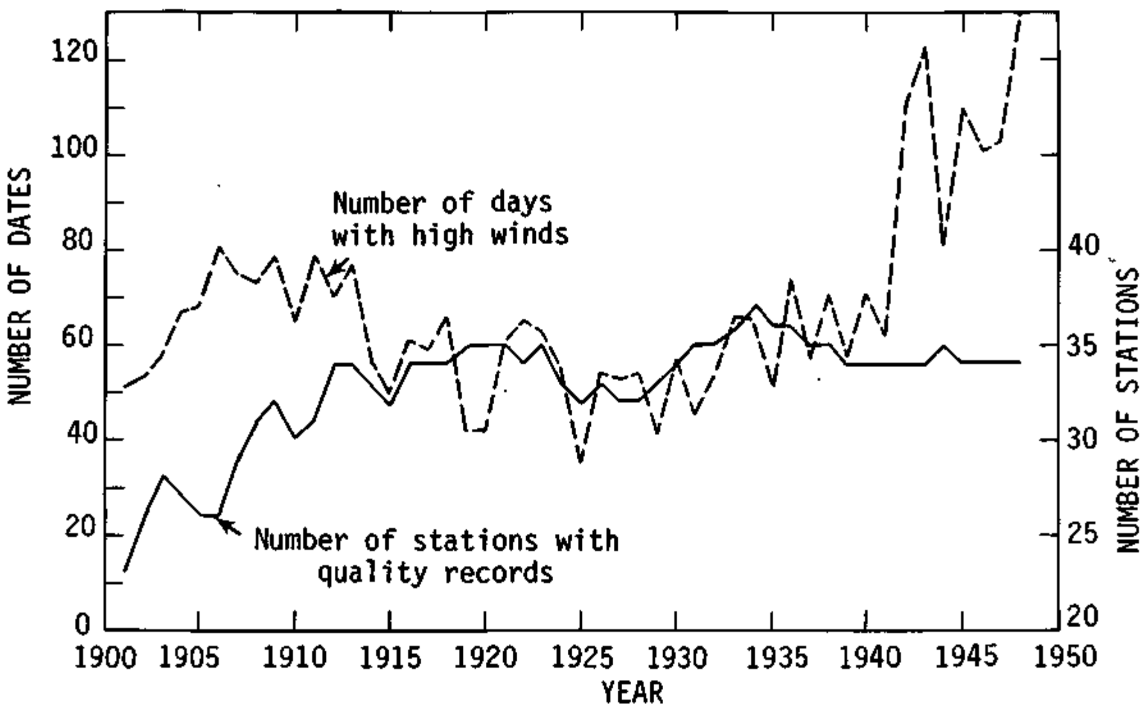

Figure 2. Annual number of days with high winds, 1901-1948, in Illinois

Table 3. Yearly Average Number of High Wind Days in Illinois during Each Season and Year Per Decade

Period	*Winter*	*Spring*	*Summer*	*Fall*	*Annual*
1901-10	17.4	23.0	16.4	11.7	68.5
1911-20	15.1	22.1	11.7	11.3	60.2
1921-30	13.3	21.0	11.7	8.0	54.0
1931-40	13.7	21.4	16.1	9.7	59.9
1941-48	22.8	37.3	22.1	17.5	99.7
1901-48 average	16.2	24.5	15.3	11.4	67.4

ted and analyzed to discern any general patterns of frequencies.

Figure 3 is the pattern that was derived, after some smoothing and adjusting for the lower (typically third, fourth, and fifth in rank) ranked months. This shows six different regions in Illinois based on the four highest ranked months of incidence of high winds.

In most of Illinois, March is the month of leading occurrence of high winds. Only in two portions of south central and east central Illinois is March replaced by April frequencies as the greatest. Inspection of figure 3 reveals that in many other areas where April does not rank first, April ranks second in south central, extreme southern, and northeastern Illinois. Clearly, March and April are the months of greatest frequency of high damaging winds in Illinois.

In essence, the large number of incidences in February make it generally the third most common month of incidences. In northwestern Illinois, the February frequencies rank second just behind March and ahead of April. In much of the southern-southwestern two-thirds of Illinois, February ranks either third or fourth.

The prevalence of high wind occurrences in the late winter-early spring period is further revealed by the frequencies in May, which are third ranked in much of east central and northeastern Illinois. Incidences in May, on a state basis, are only slightly less frequent than those in February.

In east central and northeastern Illinois, the June frequencies achieve fourth rank; November values rank fourth in extreme southern and southwestern Illinois; and January frequencies rank fourth in northwestern Illinois.

The spatial distribution of the months of greatest high wind frequencies is related to average spatial

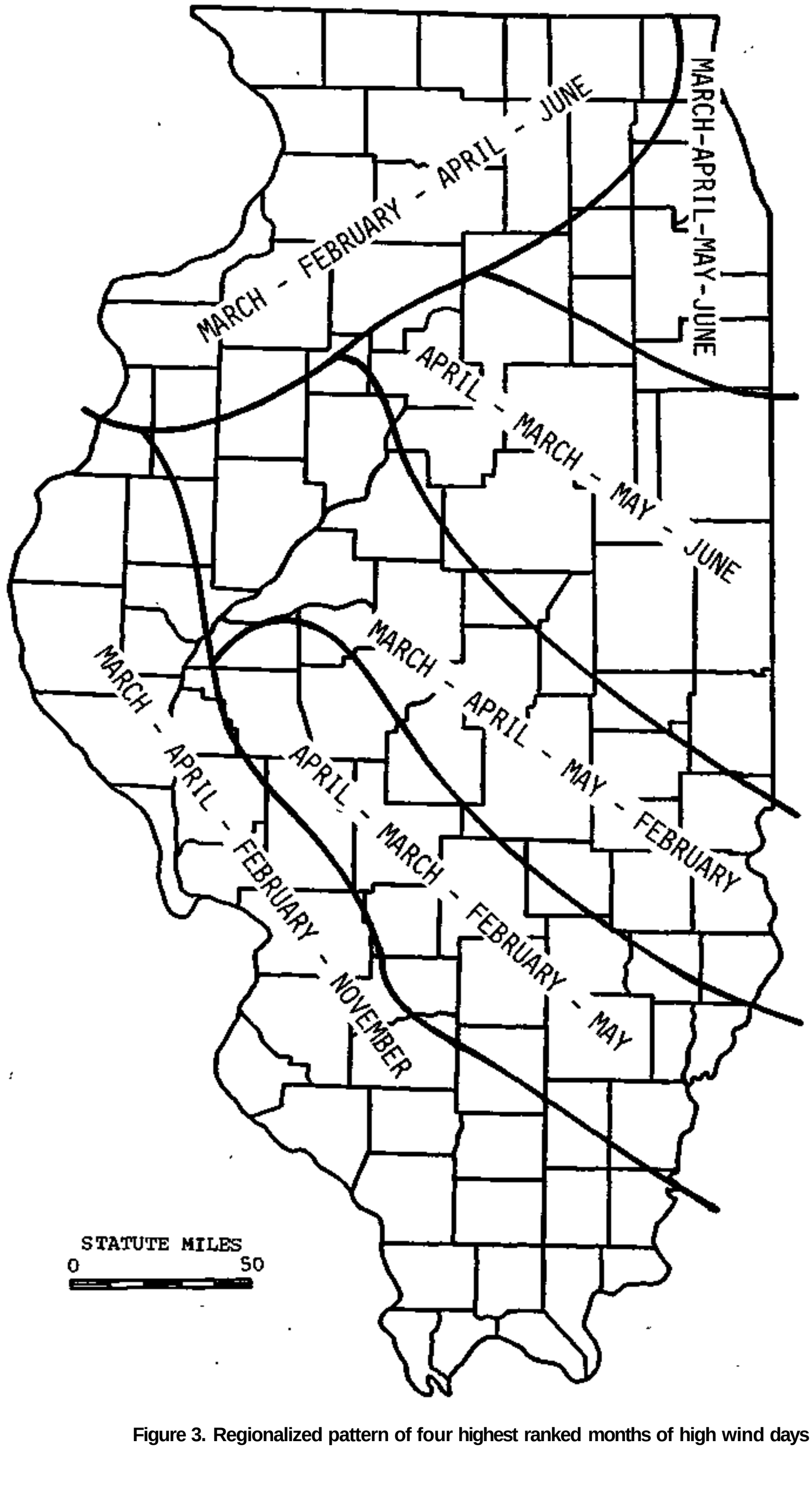

Figure 3. Regionalized pattern of four highest ranked months of high wind days

differences in high-wind-producing synoptic weather conditions. The Morgan et al. (1975) national study of frontal and pressure center climatology reveals that in February the state maximum of low pressure center passages exists across the southern third of Illinois, the area where February high wind frequencies are relatively high ranked. In March, Illinois is in a broad midwestern high frequency area for low centers, but the pattern shows two maximums, one in SW Illinois (where March high wind frequencies rank first) and one in NW Illinois (where March values also rank first). The northward intrusion of warm air is reflected in the average warm front pattern (Morgan et al., 1975) which shows an east-west maximum across southern Illinois in April (about where April values of high wind ranked first). In May, the average warm front pattern shows a maximum oriented WNW-ESE across central Illinois where April ranks first (figure 3). Squall lines attain their statewide (and annual) maximum in June across the northern third of Illinois where June values of high winds rank in the top four months (figure 3). The November national average pattern of low centers shows a maximum in western and southern Illinois where November high wind frequencies were ranked fourth.

In summary, the primary months of high wind activity reveal the general predominance of occurrences during the January through June period, with a slight secondary maximum in parts of southern Illinois in November associated with late fall cyclonic passages. Incidences of high winds are least frequent in the August-October period. As might be expected, the monthly distributions of high wind incidences, being highest in spring and the least in late summer-early fall, are very similar to the distributions of monthly average wind speeds across Illinois.

Seasonal and Annual Frequencies

The seasonal average and maximum frequencies of high wind days experienced at each of the cooperative substations appear in table 4. The seasons were defined on the basis of, winter being December through February, spring being March through May, summer being June through August, and fall being September through November.

Inspection of the average seasonal values shows that at most stations the spring season averages are the highest, followed in sequence by those of the winter season, the summer, and fall. Fall is the season of least frequent high wind days at most Illinois stations. Spring point averages are typically more than 1 day at a point and less than 3 days. Winter averages range from 1 to 2 days, and those in summer and fall are generally less than 1 day per year. A value of 0.5 indicates one high wind day occurring every other year, on the average.

At all stations, the minimum incidence of high wind days in each season was zero, and hence these minimum extremes are not listed in table 4. However, the maximum number of days per season are listed, and these generally show values three to six times greate - than the averages, indicating that seasonal frequencies of high wind days occasionally can be very large, at least in relation to the average point value.

Seasonal and Annual Patterns

Seasonal Patterns. The seasonal average point values in table 4 and the annual average and maximum point values in table 2 were plotted and used to develop statewide patterns based on the point high wind averages. The pattern based on the average point frequencies in the winter season (December through February) is shown in figure 4a. The pattern features two major highs, one in extreme southern Illinois, and the other in extreme northern Illinois, where winter snowstorms have been found to be most frequent (Changnon, 1969). Comparison of the high wind pattern with that for low centers during 1945-1959 (Chiang, 1961) reveals poor agreement, except in extreme southern Illinois where low passages are very frequent. Points in the broad area between these highs (as defined by > 1.5 days per season) have values generally from 0.5 day to 1.3 days per winter. The lowest winter averages are found in south central and east central Illinois, but there are no distinct areas of relatively low values in the winter pattern, which is best described as a flat one with two highs superimposed on it.

Figure 4b presents the pattern based on the point daily averages in the spring season. Two notable high frequency areas exist, one across central Illinois where values ranged from 2 to 3 days, and another

Table 4. Seasonal Average and Maximum Numbers of Days

Station		Winter	Spring	Summer	Fall	Station		Winter	Spring	Summer	Fall
Aledo	a*	1.0	1.8	1.2	0.6	Monmouth	a	1.2	1.8	1.1	0.7
	m*	8	10	6	5		m	9	9	4	5
Anna	a	1.6	3.2	0.6	1.1	Morrison	a	0.7	1.2	0.8	0.3
	m	9	16	3	6		m	6	7	4	2
Bloomington	a	0.9	1.4	0.6	0.5	Morrisonville	a	1.1	2.0	0.4	0.8
	m	6	9	6	5		m	l0	9	4	6
Charleston	a	1.3	3.0	0.4	0.5	Mt. Carmel	a	0.9	1.2	0.4	0.2
	m	8	15	3	4		m	8	5	6	3
Carlinville	a	1.0	2.4	0.3	0.6	Mt. Vernon	a	0.5	1.2	0.6	0.3
	m	9	16	6	5		m	8	8	7	3
Danville	a	1.2	1.6	0.7	0.4	New Burnside	a	2.1	2.5	0.6	0.9
	m	8	11	5	6		m	16	11	8	7
Decatur	a	0.9	2.0	0.8	0.6	Olney	a	1.0	1.4	0.5	0.7
	m	8	6	4	3		m	10	11	6	6
Dixon	a	0.7	1.4	1.2	0.3	Palestine	a	1.3	2.5	1.0	0.9
	m	6	13	3	3		m	l0	9	7	9
Effingham	a	0.6	1.7	0.9	0.4	Pana	a	1.4	1.7	0.8	0.8
	m	5	12	7	4		m	6	11	6	4
Flora	a	0.7	1.6	0.4	0.2	Paris	a	1.2	3.0	0.8	0.9
	m	7	8	4	2		m	9	13	6	8
Freeport	a	1.3	1.5	0.4	0.5	Pontiac	a	1.0	1.4	0.8	0.5
	m	8	9	5	3		m	9	13	7	4
Galva	a	1.3	1.2	1.0	0.6	Roberts	a	0.8	1.8	0.6	0.5
	m	7	4	3	3		m	2	10	3	3
Harrisburg	a	1.0	2.0	0.6	0.6	Rockford	a	1.6	1.8	0.9	0.5
	m	8	16	3	5		m	8	11	4	5
Hillsboro	a	0.8	1.6	0.3	0.4	Rushville	a	1.2	2.6	0.8	0.7
	m	6	8	3	3		m	6	18	7	6
Hoopeston	a	0.6	1.0	0.7	0.5	Sparta	a	.0.8	1.4	0.5	0.6
	m	3	15	7	4		m	8	15	3	5
Jacksonville	a	1.0	1.9	0.8	0.5	Sycamore	a	1.7	1.8	0.4	0.6
	m	7	11	6	4		m	6	7	4	5
Joliet	a	0.7	1.1	0.4	0.5	Urbana	a	0.9	1.7	0.8	0.5
	m	8	7	3	2		m	6	9	5	3
La Harpe	a	0.9	1.3	0.5	0.5	Walnut	a	1.2	1.1	1.2	0.4
	m	5	8	7	4		m	6	8	5	5
Lincoln	a	0.7	1.9	1.0	0.5	Waukegan	a	1.2	1.4	0.7	0.7
	m	3	7	5	6		m	9	10	5	4
Mascoutah	a	0.5	1.1	0.8	0.3	White Hall	a	0.9	2.3	0.3	0.3
	m	3	10	5	2		m	5	16	6	2
McLeansboro	a	0.8	1.4	0.5	0.5	Windsor	a	1.3	2.4	0.6	0.8
	m	7	7	7	3		m	2	6	4	3
Minonk	a	1.0	1.4	1.0	0.3						
	m	6	7	4	4						

** a = average, m = maximum*

in extreme southern Illinois of the same magnitude. Between these areas, and centered on Mount Vernon, is a low frequency area (values <1.5 days per spring). Most of the northern third of Illinois had comparable low values. The spring pattern is remarkably similar to the average pattern of low pressure center frequencies (Chiang, 1961)'. Low pressure center passages (and cold and stationary fronts) are 1) frequent in a west-east belt across central Illinois, 2) frequent in extreme southern Illinois, and 3) infrequent in a west-east belt across south central Illinois and in northern Illinois.

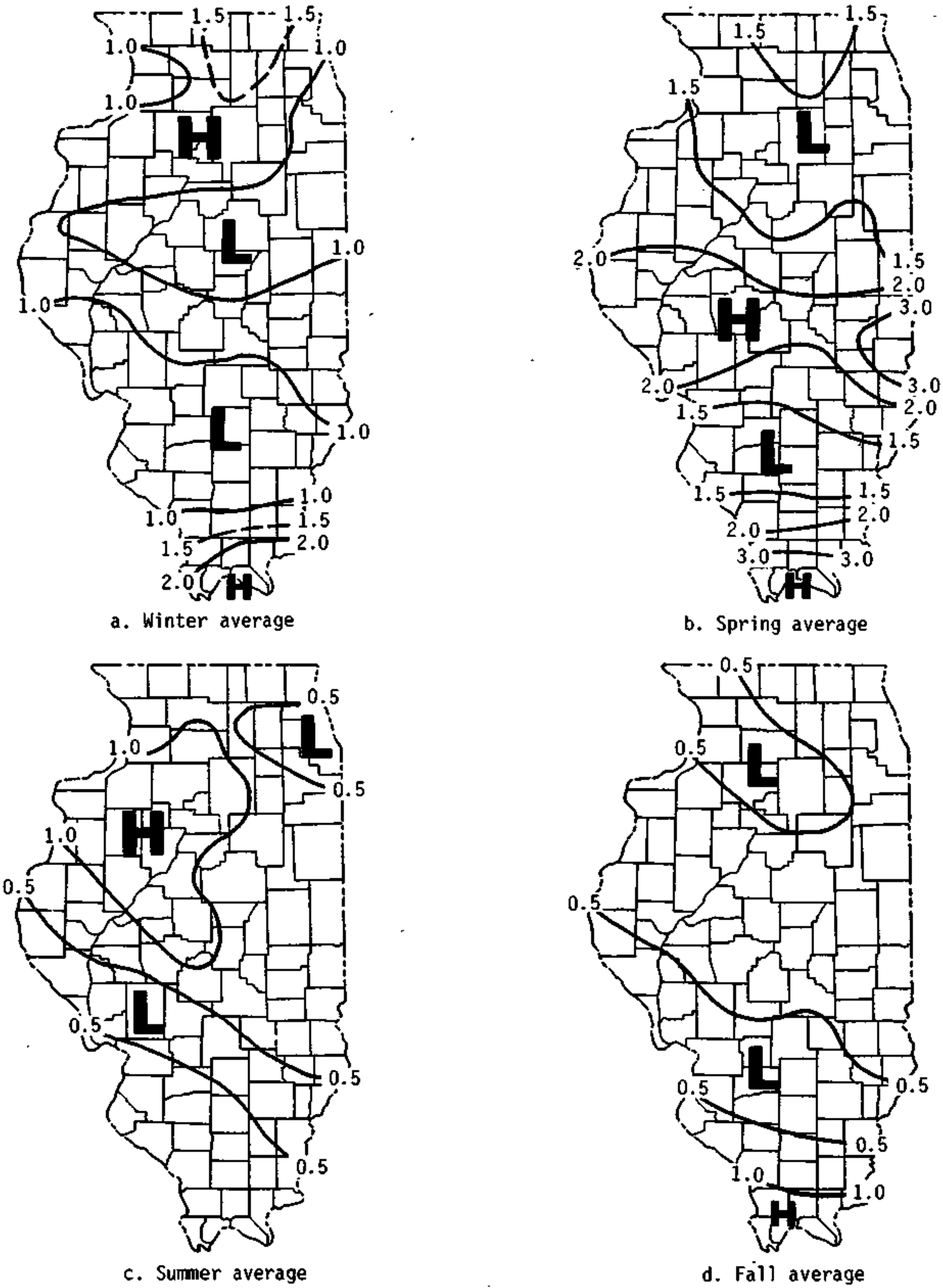

Figure 4. Patterns based on average point frequencies of high wind days by season

The summer pattern (figure 4c) is relatively featureless, particularly when compared with the variations found in the winter and spring patterns. Most summer point averages range from 0.5 to 1.0 high wind days. Slightly lower values are found in an area extending from western to southeastern Illinois. The area of greatest frequency, greater than 1 day per year, is found in northwestern Illinois where summer thunderstorm and hailstorm frequencies are also high (Changnon, 1967a). Chiang (1961) shows this area to be one of frequent frontal activity, and Morgan et al. (1975) show it to be a place of frequent squall line activity. Hence, the high wind maximum reflects greater incidence of strong convective activity in the area.

Figure 4d for the fall season averages also shows a generally flat pattern. Fall values are the lowest of all the seasons except in extreme southern Illinois where fall averages exceed summer values. The lowest fall values, slightly less than 0.5 days per year at a point, are found in northwestern Illinois and across south central Illinois. The highest values in fall are found in extreme southern Illinois. In the southern third of Illinois, the fall high wind pattern closely resembles that found in the winter season, due to the more frequent passage of deep low pressure centers across southern Illinois in late fall and winter (Chiang, 1961). There is a greater fall incidence of thunderstorms in extreme southern Illinois than elsewhere (Changnon, 1957) which probably helps produce a greater frequency of high wind days there.

Annual Patterns. The summation of the four season average values into the annual average values, as shown in table 2, was plotted to produce the annual average pattern, shown on figure 5a. The pattern is based on point average annual values of high wind days. The values range from highs of 6.5 days per year at Anna in extreme southern Illinois to lows of slightly less than 3 days per year in south central Illinois and in extreme northeastern Illinois. Thus, the high to low range in Illinois is more than 100%. The primary highs include 1) the high of extreme southern Illinois, 2) a major east-west oriented high across central Illinois; and 3) the SW-NE oriented high in northwestern Illinois.

Comparison of this average annual pattern of high wind days (figure 5a) with those for thunderstorms and hailstorms (Changnon, 1967a) reveals interesting similarities. In many respects, the three high frequency areas shown in figure 5a are comparable to the highs found in the average pattern of hail days. The thunderstorm pattern in Illinois is also somewhat similar with the greatest thunderstorm frequency being in southern and western Illinois and the lowest frequency in northeastern Illinois. Differences between the average thunderstorm pattern and the high wind pattern should be expected, however, because certain high wind events are results of deep low pressure center passages or winter storms occurring without thunderstorms.

The three major highs in the average damaging wind pattern (figure 5a) appear attributable to spatial variations in certain synoptic weather conditions. The high frequency center in extreme southern Illinois is largely related to the high frequency of passages of low centers there in three seasons, winter, spring, and fall. The east-west oriented high across central Illinois is due to a maximum of low pressure center passages (and frontal activity) in that area during spring. The high in NW Illinois is related to two factors, a maximum of frontal and squall line activity there in summer and a maximum of severe winter storms (and deep lows) there in winter.

Another expression of the annual frequency of high winds, as based on the point maximum number of days in any one year (1901-1948 period), is portrayed in figure 5b. These values also appear in table 2. Stations with less than 30 years of record are denoted because unrepresentative (too low) extreme values appeared at several of these stations, reflecting the effect of inadequate sampling. The pattern, in many aspects, is like the average pattern (figure 5a). The highest values are in extreme southern Illinois, and a high extends across central Illinois with an east-west low in frequency across south central Illinois.

Daily Frequencies of High Wind Speeds at First Order Stations

First order stations did not record, as did the cooperative substation observers, the local incidence of high (damaging) winds. However, the first order stations had instruments that recorded actual wind speeds, and these were investigated. Since wind-caused crop damage begins to occur at about 40 mph and damages to property begin at about 45

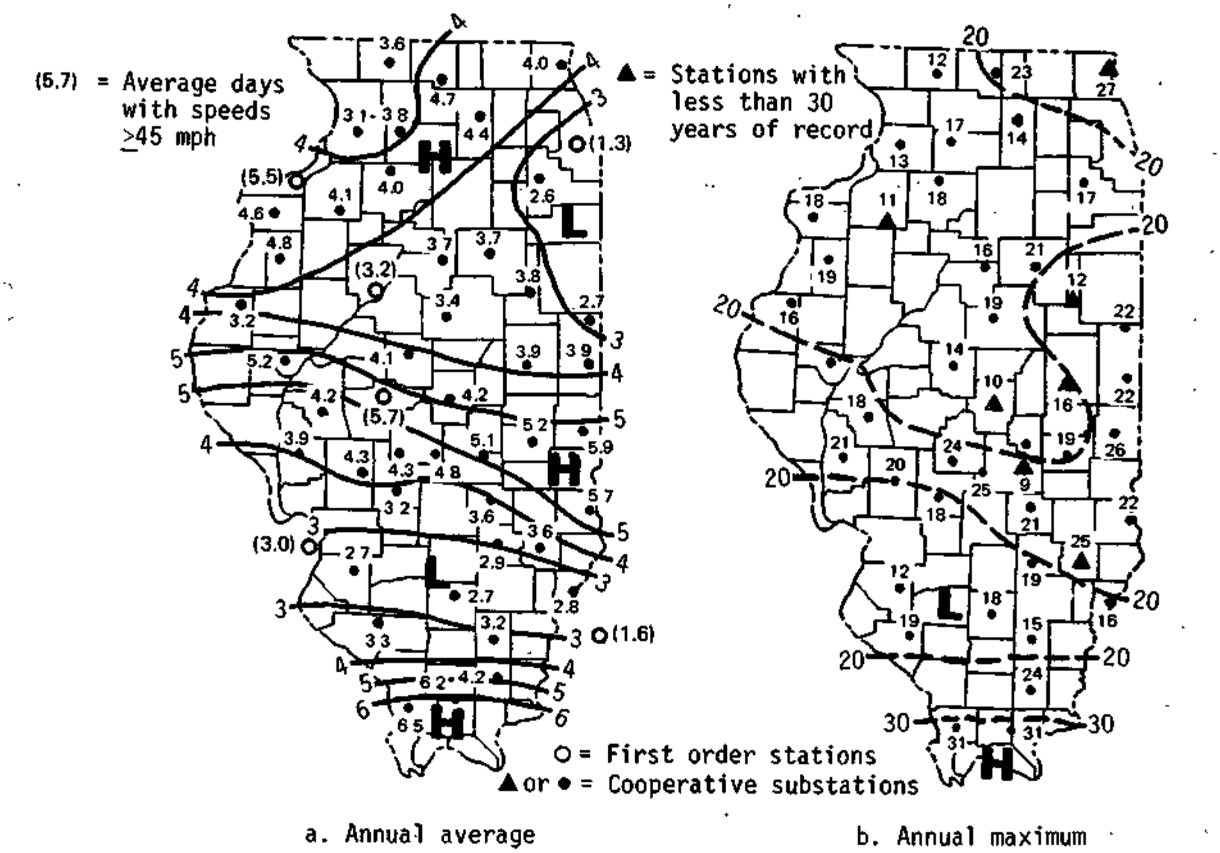

Figure 5. Patterns of annual average and annual maximum frequencies of high wind days

mph, frequencies of days with winds at different levels, 40, 45, 50, and 60 mph, were analyzed for the six first order stations (see figure 1). The number of days in the 1950-1978 period with speeds in the 40-44 mph, 45-49 mph, 50-59 mph, and ≥ *60* mph categories are shown in table 5. Notable are the considerable differences in the station frequencies. High values exist at Springfield and Moline in all four speed classes, and much lower incidences occur at Chicago and Evansville. In all categories, the spring values are the highest seasonal values.

Since most wind-caused damage in all seasons is to property and since property damage begins to occur with speeds ≥ 45 mph, the values of ≥ 45 mph in table 5 were totaled and averages derived as shown in table 6. These averages were compared with seasonal and annual high wind patterns (figures 4 and 5a) to investigate the general validity of the first order station values and also to evaluate the reality of the high wind day values of the substations.

The annual averages of the first order stations are shown in parenthesis in figure 5a to facilitate this comparison. The values at Chicago and Evansville seem too low by about 1 day per year, or nearly 40%. These lower-than-expected values occur at Chicago Midway Airport (inside the city) in all four seasons, indicating urban exposure influences (sheltering) have likely acted to reduce extreme wind occurrences. Thorn (1960) has shown how urban sites have markedly lower extreme winds than do rural (airport) sites. At most of the other 5 stations, the 1950-1978 data were collected at relatively open, rural airport sites. At Evansville the most unrealistic (too low) seasonal values are in winter and spring, although the summer and fall values are slightly lower than nearby substation values would indicate. An exposure problem or calibration problem is suggested.

The seasonal and annual averages at Moline, Peoria, Springfield, and St. Louis fit the high wind day patterns extremely well, helping to support the

Table 5. Frequency of Days with High Winds in Different Speed Classes at First Order Stations in 1.950-1978

	Winter	Spring	Summer	Fall	Total
Number of days with winds of 40 to 44 mpb					
Chicago	20	37	18	18	93
Peoria	23	57	24	30	134
Moline	34	97	37	34	202
Evansville	13	40	13	10	76
St. Louis	33	68	27	19	147
Springfield	43	111	51	42	247
Number of days with winds of 45 to 49 mpb					
	Winter	*Spring*	*Summer*	*Fall*	*Total*
Chicago	4	13	5	5	27
Peoria	8	22	15	14	59
Moline	13	50	20	15	98
Evansville	9	16	6	3	34
St. Louis	9	24	13	10	56
Springfield	17	51	30	19	117
Number of days with winds of 50 to 59 mpb					
	Winter	*Spring*	*Summer*	*Fall*	*Total*
Chicago	2	5	1	1	9
Peoria	2	12	8	7	29
Moline	5	26	11	7	49
Evansville	4	4	2	0	10
St. Louis	6	10	4	4	24
Springfield	7	17	13	8	45
Number of days of winds ≥ 60 mph					
	Winter	*Spring*	*Summer*	*Fall*	*Total*
Chicago	0	0	0	1	1
Peoria	0	1	3	3	7
Moline	0	10	4	1	15
Evansville	0	0	1	0	1
St. Louis	2	4	1	2	9
Springfield	0	3	2	0	5

Table 6. Average Frequency of Days with Winds 45 mph or Higher at First Order Stations in 1950-1978

	Winter	*Spring*	*Summer*	*Fall*	*Annual*
Chicago	0.2	0.7	0.2	0.2	1.3
Peoria	0.3	1.2	0.9	0.8	3.2
Moline	0.6	2.9	1.2	0.8	5.5
Evansville	0.5	0.7	0.3	0.1	1.6
St. Louis	0.6	1.3	0.6	0.5	3.0
Springfield	0.8	2.4	1.6	0.9	5.7

reality of the substation data. In fact, the first order station data help define the patterns. The Springfield annual average of 5.7 days (with winds ≥ 45 mph) supports the east-west high of >5 days extending across Illinois (figure 5a). The high Moline value (5.5 days) suggests a localized high within the SW-NE oriented maximum in northern Illinois.

High Winds with Thunderstorms

The occurrence of high wind events (days) on days when cooperative observers reported thunderstorms was investigated to define the relationship between thunderstorms and high winds. Earlier investigations (Changnon, 1962) had established the frequencies of relationships of days with hail with days of thunderstorms, showing that approximately 90% of all hail events in Illinois occurred with thunderstorms.

Seasonal and annual values showing the frequency of high wind events associated with thunderstorms (on the same day) somewhere in Illinois appear in table 7. As expected, the coincidence between thunderstorms and high winds is greatest in summer (68% of all high wind days were with thunderstorms at the same point somewhere in Illinois), and was least in winter. Only 8% of the days with high winds in winter were associated with thunderstorms, and 26% were with thunderstorms in both spring and fall. The annual values show that 30% of the high wind events came when thunderstorms also occurred. In general this shows that thunderstorms are likely the major producers of damaging but non-tornadic winds in summer but are not a major factor in the other seasons. This further reveals that deep low pressure centers are the primary cause of high wind events in the non-summer months.

Durations of High Wind Events

As noted in the introduction, studies of wind speeds and damages to vegetation, crops, and property show such damages generally occurred when wind gusts exceeded speeds ranging from 40 to 50 mph. Information on the exact duration, on a day with "high winds," of the high wind speeds was desired. However, the only continuously recorded, long-term wind speed data available was that for Urbana (central Illinois) for the 1970-1979 period based on an aerovane type anemometer at 60 ft elevation. The data could be resolved for 1-minute intervals on a continuous strip chart and were analyzed on a seasonal basis for all events when the wind speeds exceeded 40 and 50 mph.

Most of the analysis focused on the 1-minute gust values ≥ 40 mph. The analysis included determination of the daily spans, defined by the beginning (or initial) gust of ≥ 40 mph and ending of the

Table 7. Yearly Frequencies of Days with High Winds Occurring in Illinois with Thunderstorms and without Thunderstorms during 1924-1948

	Winter		*Spring*		*Summer*		*Fall*		*Annual*	
Year	*HW +TRW**	*HW only***	*HW +TRW*	*HWO*	*HW +TRW*	*HWO*	*HW +TRW*	*HWO*	*HW +TRW*	*HWO*
1924	4	17	6	12	9	6	3	6	22	41
1925	0	6	5	11	5	4	1	1	11	22
1926	2	16	2	13	5	11	1	5	10	45
1927	0	10	10	13	5	3	6	4	21	30
1928	1	11	3	14	13	5	2	8	19	38
1929	1	11	6	11	6	0	0	4	13	26
1930	0	10	2	21	5	5	4	12	11	48
1931	0	3	1	13	8	8	6	5	15	29
1932	2	8	2	17	14	2	2	5	20	32
1933	0	19	7	14	8	2	3	15	18	50
1934	0	13	1	22	10	7	4	6	15	48
1935	0	10	8	23	6	3	0	3	14	39
1936	2	15	5	16	10	12	1	13	18	56
1937	3	15	6	11	12	5	1	3	22	34
1938	0	15	10	19	13	7	2	7	25	48
1939	2	11	4	11	14	5	2	8	22	35
1940	0	19	6	18	9	6	4	7	19	50
1941	0	17	5	15	11	3	3	10	19	45
1942	1	22	14	29	21	0	4	18	40	69
1943	4	31	10	36	18	7	4	13	36	87
1944	3	13	7	22	18	9	2	7	30	51
1945	1	18	15	27	17	4	5	20	38	69
1946	3	31	5	27	5	8	5	12	18	78
1947	4	24	14	26	14	7	4	11	36	68
1948	3	29	12	35	20	9	5	17	40	90
Year averages	1.4	15.8	6.6	19.0	11.0	5.5	3.0	8.8	22.0	49.1
Percent of total	8	92	26	74	68	32	26	74	30	70

** HW + TRW = High winds plus thunderstorms in Illinois*
** HW only = High wind without thunder in Illinois*

gusts. Since high gusts were often intermittent, the span was typically longer than the duration of speeds ≥ 40 mph. Table 8 shows the distribution of the daily spans. For example, there were 38 winter days and on 9 of them the span was only 1 minute, but on one day the speed ≥ 40 mph lasted for 23 hours and 3 5 minutes.

The analysis also included the length of those periods when winds remained ≥ 40 mph, called "discrete" periods. The results of these appear in table 9. In winter there were 196 discrete events ≥ 40 mph; 160 of these were only 1 minute long and 15 were 2 minutes long.

A third temporal aspect investigated was the length of periods between the discrete (≥ 40 mph) periods. The durations of these lower wind speed periods between the high values, when their duration was ≤60 minutes, are shown in table 10. In winter there were 83 such in-between periods and 27 of these were in the range from 1 to 5 minutes.

Tables 11 and 12 summarize the key values from tables 8, 9, and 10. The median duration of the daily spans is 4 hours and 10 minutes in winter and within this period there are, on the average, 5 discrete ≥ 40 mph periods, each typically 1 minute long. The median duration of the shorter (<60 minute) periods between 40 mph periods is 9 minutes. The spring and fall values (table 11) are similar with spans slightly over 2 hours and with 6 to 7 discrete periods within this span. Infrequently,

Table 8. Distribution of Durations of Daily Spans of Time (Begin and End) with ≥ 40 mph

Season	*Number of days*	*1 min only*	*2 min to 1 hr*	*1 hr to 2 hr*	*2 hr to 3 hr'*	*3 hr to 4 hr*	*4 hr to 5 hr*	*5 hr to 6 hr*	*6 hr to 7 hr*	*7 hr to 8 hr*	*8 hr to 10 hr*	*10 hr to 12 hr*	*>12 hours*	*Maximum*
Winter	38	9	4	3	2	0	3	2	3	2	1	3	6	23:35
Spring	61	16	6	5	6	6	1	4	3	2	3	4	5	17:40
Summer	16	7	7	0	1	1	0	0	0	0	0	0	0	3:27
Fall	17	5	2	1	2	1	1	1	3	0	1	0	0	9:31

Table 9. Frequency of Distribution of Durations of Discrete Periods
With Speeds ≥ 40 mph at Urbana, 1973-1979

	Totals	*1 min*	*2 min*	*3 min*	*4 min*	*5 min*	*6 to 30 min*	*31 to 60 min*	*1 to 2 hr*	*2 to 3 hr*	*3 to 6 hr*	*>6 hr*	*Maximum*
Winter	196	160	15	6	2	0	2	2	2	0	4	3	23:35
Spring	412	344	27	13	3	2	8	2	5	4	2	2	6:32
Summer	36	31	1	2	0	0	2	0	0	0	0	0	0:18
Fall	100	82	15	1	0	0	1	0	1	0	0	0	1:04
Total	744	617	58	22	5	2	13	4	8	4	6	5	

Table 10. Frequency Distribution of Times between Discrete Periods for Durations ≤60 Minutes
(1975-1979) Based on ≥ 40 mph at Urbana

	Total	*1-5 min*	*6-10 min*	*11-15 min*	*16-20 min*	*21-25 min*	*26-30 min*	*31-35 min*	*36-40 min*	*41-45 min*	*46-50 min*	*51-55 min*	*56-60 min*
Winter	83	27	15	10	5	10	1	4	4	2	2	1	2
Spring	200	59	38	29	19	20	9	9	5	3	4	2	3
Summer	19	10	3	1	1	1	0	1	1	1	0	0	0
Fall	67	17	22	11	4	3	3	1	3	1	0	1	1

Table 11. Various Characteristics of Events When Gusts ≥ 40 mph at Urbana, 1970-1979

	Median duration of daily spans (hr and min)	*Average number of discrete periods per span**	*Median duration of discrete periods***	*Median duration between discrete periodst*
Winter	4:10	5	1 minute	9
Spring	2:34	7	1 minute	11
Summer	0:05	2	1 minute	5
Fall	2:03	6	1 minute	9

** Span is the period per day comprising the beginning and ending gusts >40 mph*
*** Discrete period is one when wind ≥ 40 mph continuously*
t Based on durations ≤60 minutes, tbis excludes a few large differences

Table 12. Various Characteristics of Events When Gusts 3*50 mph at Urbana, 1970-1979

		Number of discrete periods sorted by duration (minutes)						*Number of days having various frequencies of discrete gusts*			
	Number of days	*1 min*	*2 min*	*3 mm*	*4-10 min*	*11-40 min*	*Maximum duration*	*1 discrete per day*	*2 discrete per day*	*3 discrete per day*	*>4 discrete per day*
Winter	19	40	2	2	4	3	32 min	4	8	3	4
Spring	18	21	4	0	4	1	9 min	10	5	2	1
Summer	4	3	1	1	0	0	3 min	3	1	0	0
Fall	1	4					1 min	0	0	0	4
Total	42	68	7	3	8	4		17	14	5	9

the discrete periods are quite long (table 9), but the preponderance (and median) are only 1 minute long (tables 9 and 11).

Incidences of winds ≥ 50 mph were also studied. Table 12 shows there were 42 such days in 1970-1979 (4 per day on the average). In winter there were 19 days and on 8 of these there were 2 discrete periods. These discrete (≥ 50 mph) periods most often lasted only 1 minute (68 of 90, see table 12), although on one winter day gusts ≥ 50 mph lasted 32 minutes.

It is obvious in tables 11 and 12 that summer extreme wind events at a point are short-lived. The 40 mph events typically last only 5 minutes and have two 1-minute gusts in this span, reflecting their short-lived thunderstorm origin. The high wind events in the other three seasons, which are most often related to passages of deep low pressure centers, lasted much longer (typical spans of 2 to 4 hours) with 5 to 7 discrete 1-minute high wind gusts occurring intermittently in these multi-hour periods.

Table 13 presents the diurnal frequency of the Urbana gusts ≥ 40 mph. In the colder seasons (fall, winter, and spring), the maximum occurrences came in the daytime, 0900-1800, with minimums at night. Although these events are largely produced by low centers without a daytime maximum, the daytime maximums of high winds suggest the added influence of daytime heating on the strength of the large scale circulation. The summer distribution shows a late afternoon maximum, the time when convective activity and thunderstorms are greatest.

Table 13. Diurnal Distribution of ≥ 40 mph Gusts at Urbana, 1970-1979*

3-Hour (CDT) periods	*Winter*	*Spring*	*Summer*	*Fall*
00-03	15	10	2	4
03-06	16	7	1	3
06-09	17	17	1	2
09-12	28	36	4	13
12-15	27	42	3	10
15-18	22	38	5	10
18-21	18	20	5	5
21-24	15	14	4	5

** All gust occurrences (1 or more) in a 3-hour period per day were counted as one event.*

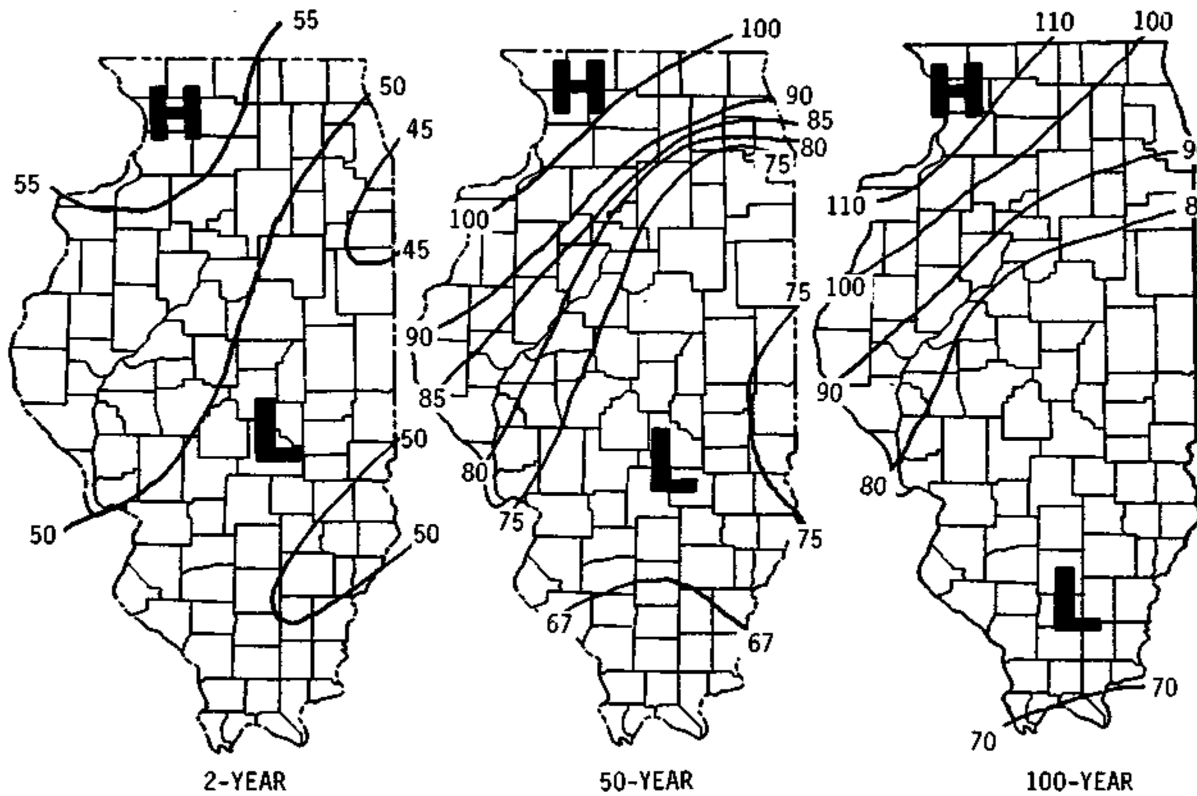

Figure 6. Wind speeds (mph) exceeded at least once every 2, 50, and 100 years

Extreme Winds

Thorn (1960) made a statistical analysis of annual extreme wind speeds ("extreme mile speed") at first order stations in the U. S. He converted the data for anemometer type differences and reduced it to a standard 30-ft elevation. The annual extreme values were used to develop likely values expected for various mean recurrence intervals. The resulting patterns for the 2-, 50-, and 100-year recurrence intervals and for Illinois appear in figure 6. The southern and eastern areas have lower values than those found in western and northern Illinois. For example, at least once in a 50-year period the point maximum mile speed will be in the 100 to 110 mph range in extreme NW Illinois, whereas it will be in the 65 to 67 mph range in extreme southern Illinois. Sharp differences in the expected very high speeds, often used in structural design, exist across north-central Illinois.

AREAL DISTRIBUTIONS

Days with Extensive High Wind Occurrences

Days with the largest numbers of high wind reports during the 1901-1948 period were identified and plotted to reveal the areal extent of cold season and warm season days with extensive outbreaks of high winds. The results presented consider the six most extensive days in the colder half year (October-March) and the six days in the warmer half year (April-September) that had the greatest number of point high wind reports. The incidences of hail and thunder were also plotted for the stations.

Figure 7 reveals the daily patterns in the colder half year, and dashed lines help define the areal extent of the high wind areas. Shown on each map

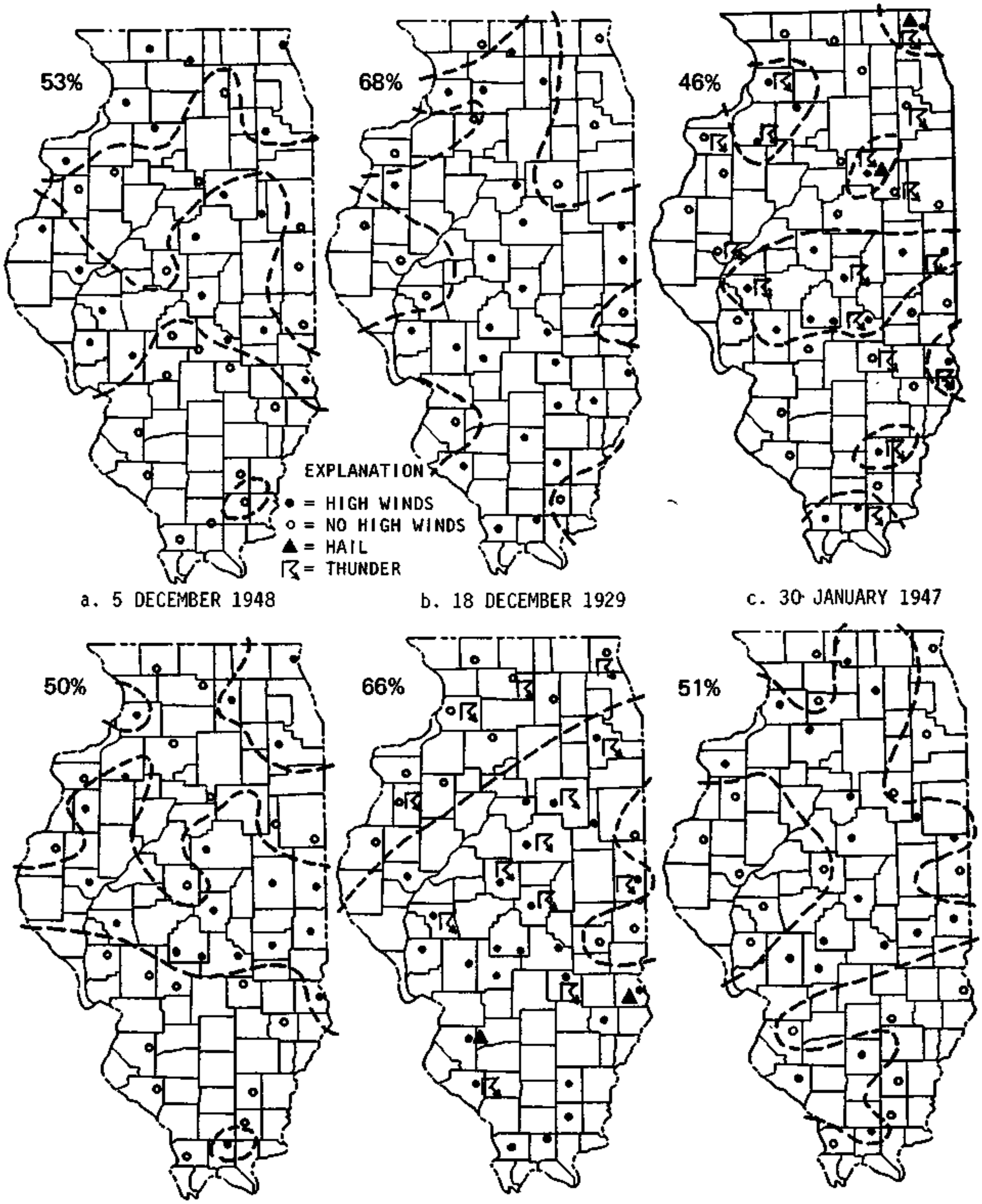

Figure 7. Six days with most extensive high wind reports in colder half year

Table 14. Dates in 1901-1948 with Extensive High Wind Reports in Illinois

	Associated thunderstorms	*Number of stations with high winds*	*Nature of areal distributions*	*Percent of total quality stations with high winds*	*Estimated area (mi^2) with higb winds*	*Illinois areas of occurrence*			
						North	*North central*	*South central*	*South*
Cold season									
5 Dec 1948	No	20	Broad	53	29,800	√	√	√	√
18 Dec 1929	No	25	Broad	68	38,400	√	√	√	0
30 Jan 1947	Yes	17	Scattered	46	26,000	√	√	√	√
14 Feb 1946	No	19	Broad and scattered	50	28,200	√	√	√	√
19 Mar 1918	Yes	25	Broad	66	37,200	√	√	√	√
25 Mar 1930	No	19	Broad	51	28,700	√	√	√	√
Warm season									
1 May 1942	Yes (hail)	18	Broad	47	26,500	√	√	√	√
9 May 1927	Yes (hail)	16	Broad and scattered	46	26,000	√	√	√	√
10 May 1934	No	26	Broad	68	38,400	√	√	√	√
1 Jun 1936	Yes	10	Scattered	27	15,200	0	√	√	√
10 Jun 1947	Yes	12	Broad and scattered	30	16,900	√	√	0	0
23 Jul 1908	Yes	10	Scattered areas	29	16,300	√	√	√	0

is a percent indicating the number of stations with high winds expressed as a percent of total quality stations in that year. Inspection of figure 7a shows that high winds hit many central and northern Illinois stations on 5 December 1948, and 53% (20) of the 38 stations in 1948 with good data had high winds.

Table 14 summarizes the material on figure 7. On each of these six days more than 46% of Illinois expressed damaging winds. The patterns for the two December days (figures 7a and 7b) were related to the passage of low pressure centers across Illinois and were without the occurrence of convective (thunderstorm) activity. These indicate the large areal extent of high damaging winds that can occur under these conditions. A different type of extensive day is illustrated by the pattern for 30 January 1947 when 46% of Illinois had high winds, but the distribution was scattered and was obviously associated with outbreaks of thunderstorms.

Figure 8 presents the extensive patterns of high winds reported in the warm season months. Table 14 and figure 8 reveal most were with major outbreaks of strong convective activity as noted by the extensive simultaneous occurrence of thunderstorms and hail. On these maps, the stations reporting thunderstorms and hail are also shown. Figure 8c for 10 May 1934 reveals a different warm season situation where 68% of Illinois had high winds without strong convective activity. The areal extent of high winds on warm season days with extensive damaging winds is generally less than that on cold season days. The top six days in the warm season included three with values of 27, 29, and 30% state coverage (table 14).

Concern over occurrences (and detection) of high winds during the prime crop damage months (July-August) led to the plotting of the days with the most extensive high wind occurrences in these two months (excluding 23 July 1908, shown in figure 8e). The six most extensive in July are portrayed in figure 9a-f. Two high wind areas (based on six stations) appeared in 14 July 1933 (figure 9a), and interestingly they did not occur in thunderstorm areas, but rather to the east of the thunderstorm activity. A similar situation appeared on 25 July 1925; however, on 22 July 1948 (figure 9b) the high winds occurred inside the areas of thunderstorm (and hail in NW) activity. A swath-like outbreak of high winds occurred on 23 July 1944 (figure 9c), but not all thunder areas on this date had high winds. Swath-like areas of high winds are apparent on most July day patterns.

A different type of pattern was displayed on 27 July 1947 (figure 9e). Here, two areas of high winds occurred within two distinctly separate zones of thunderstorms, and a close 1:1 association with thunder is indicated. A similar close association is

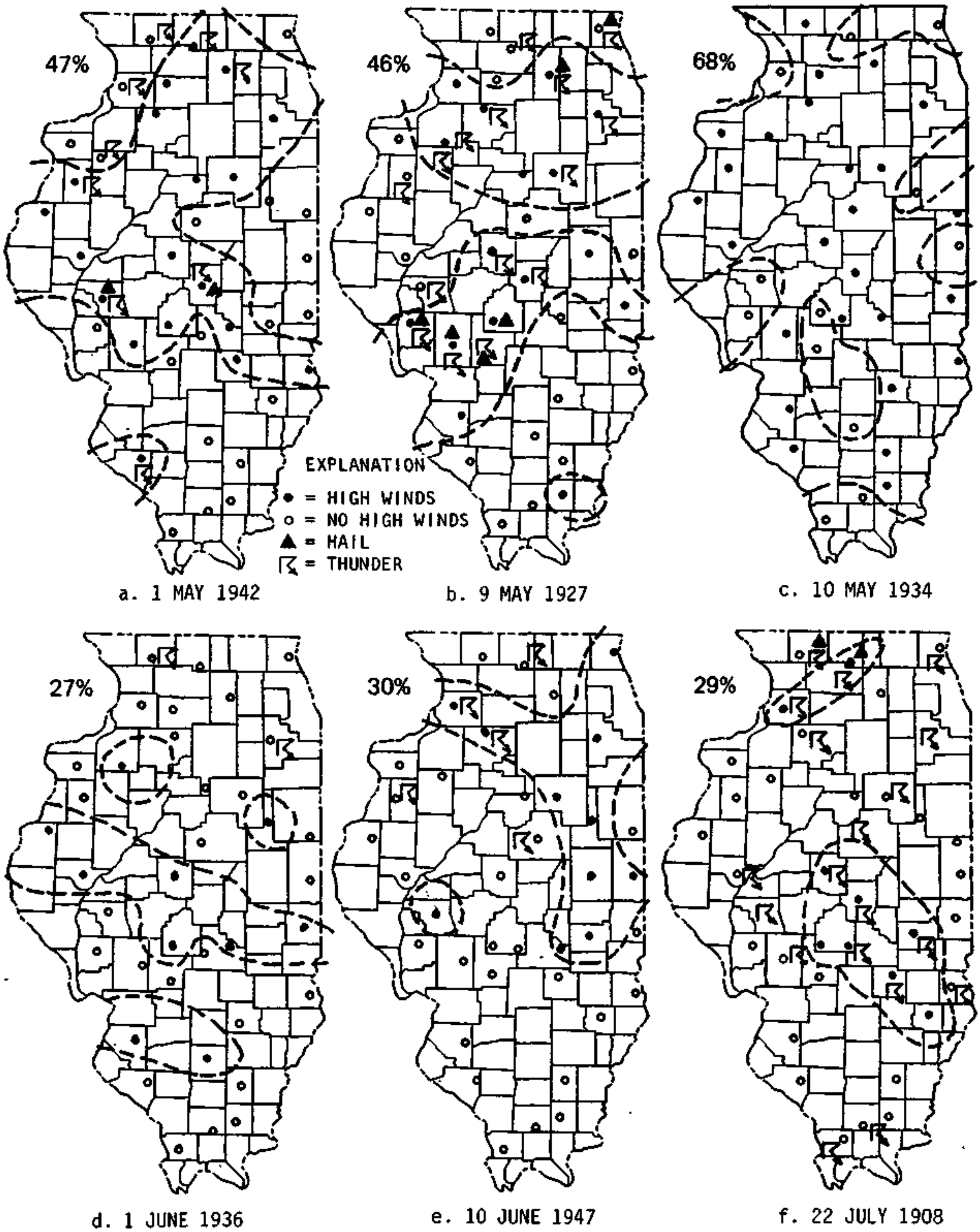

Figure 8. Six days with most extensive high wind reports in warmer half year

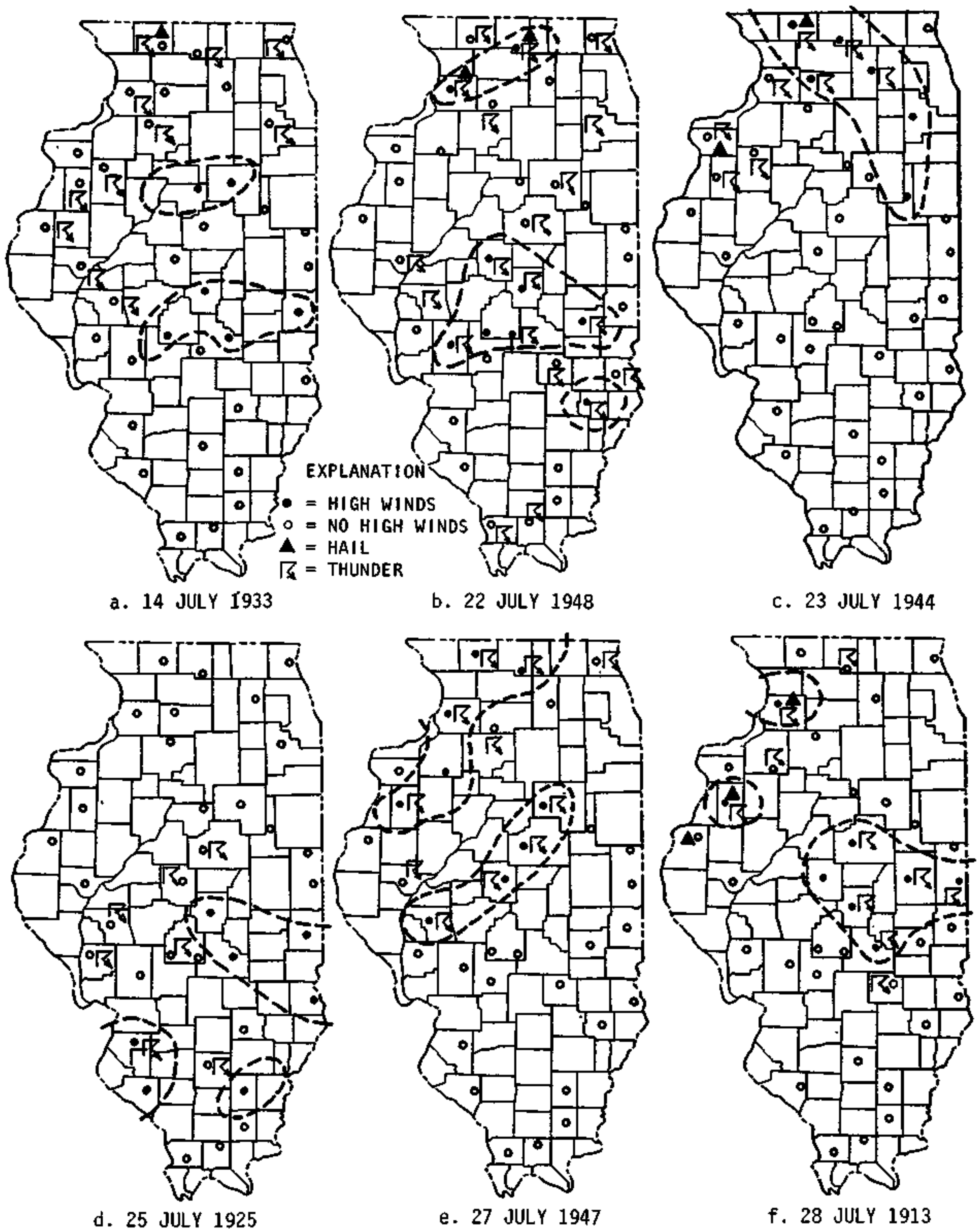

Figure 9. Six days with most extensive high wind reports in prime crop damage months (July-August)

Table 15. The Frequency of Stations with High Winds Per Day
Based on 42 Stations and Data for Illinois for 1924-1948

Number of stations with high winds	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
1	81	80	96	109	89	99	82	63	55	43	68	57	922
2	38	29	44	37	33	51	20	11	16	13	24	21	337
3	14	10	20	24	13	18	9	7	3	7	15	13	153
4	8	7	24	16	11	17	5	2	3	5	5	3	106
5	3	4	16	10	8	7	3	1	4	3	5	2	66
6	3	8	9	5	4	9	2	1		1	3	1	46
7		3	5	6	2	1	1				4	2	24
8	5	4	5	4		3	1				3		25
9	2	5	5	7		1	2		1		2		25
10	1	2	3	3	3	1	1				2	2	18
11	2	3	5	2							3		15
12	1		1	2		1							5
13		1	3	1	1								6
14	2	1	2		2								7
15	1			3									4
16			1		1						1		3
17		3									1		4
18	1		1	1	1						2		6
19		1	1										2
20				1							1	1	3
21													0
22											1		1
23													0
24													0
25			1									1	2
26					1								1
Totals	162	161	242	231	169	208	126	85	82	72	140	103	1781

found in figure 9f. The important findings are that the more major high wind days in summer often have multi-county (2 to 6 station) areas of high winds occurring apparently throughout the area. Isolated (1 station) events occur, but are not common. These areas of outbreaks seem to occur either inside areas of intensive thunder and hail activity, as might be expected, or in areas to the east of thunderstorm activity. The larger outbreak areas also tend to be swath like, and elongated E-W, suggesting a westerly moving outbreak of high winds.

Areal Extent of High Winds on a Daily Basis

The number of stations in Illinois reporting high winds on each date during 1924-1948 was counted to get information on the areal distributions. Table 15 shows the number of times high wind days occurred in Illinois, as based on 1, 2, 3, 4, or more station reports per day. Distinct differences between months is revealed in table 15. The greater frequencies of days with more widespread high wind events are evident in the November-May period. Extensive daily outbreaks are least frequent in September and October.

If one expresses the number of days with only 1 station having high winds (a total of 922) as a percent of total days (1781), it reveals that 59% of all high wind days were based on an event at only one point (station). The number of days with 2 stations (337) is 19% of the total, and those with 3 stations is 9%. Hence, 87% of all high wind days in Illinois were cases when only 1, 2, or 3 stations reported high winds. If one assumes that each quality station represents approximately 1300 square miles (56,400 square miles divided by 43 stations), one can utilize the data in table 15 to calculate estimates of the areal extent of high winds. The great preponderance

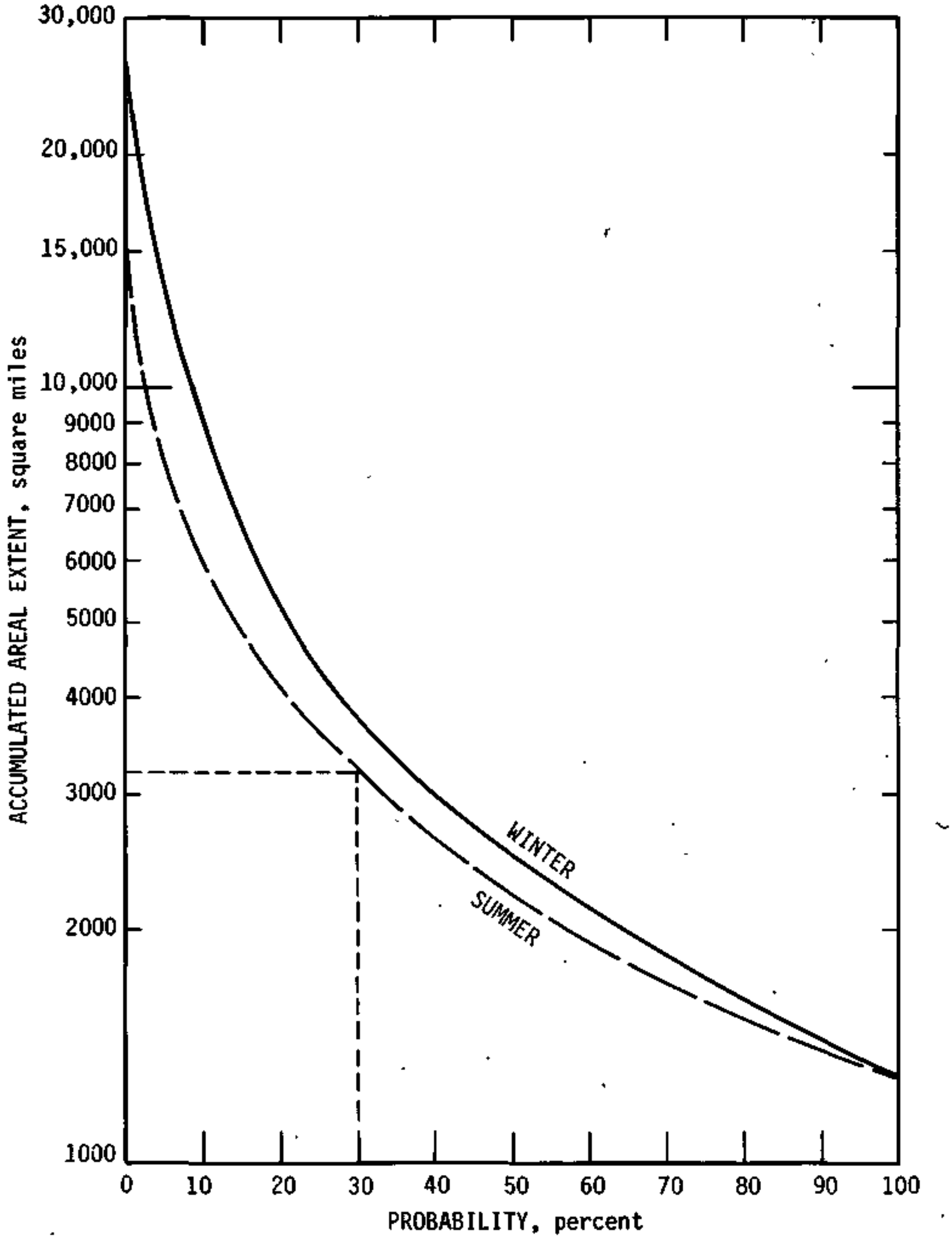

Figure 10. Probabilities for areal extent of high winds in summer and winter

of days with only 1 or 2 station reports (78%) indicates that most high wind outbreaks are over areas of 3000 square miles or less.

An analysis of the frequency of the areal extent of high winds was based on the assumption that each station represented high winds over 1300 square miles. The seasonal values calculated from table 15 allowed development of point/areal relationships. Data were analyzed for the state of Illinois with the goal of developing relationships for estimating the likely areal extent of high winds, given point incidences are known. These relationships describe the climatology of the daily events and should be useful for estimating the areal extent of high wind outbreaks in Illinois and other states of comparable climate, given the point frequencies are available from historical data.

The results in figure 10 reveal the average winter

Table 16. Frequency of Days of High Winds during 1901-1948 in Various Areas

Districts	*Winter*	*Spring*	*Summer*	*Fall*	*Annual*
Northwest	4.3	6.7	3.4	2.5	16.9
Northeast	3.7	4.5	1.7	1.7	11.6
West	3.5	4.8	2.3	2.0	12.6
Central	3.2	5.2	2.9	1.8	13.1
East	2.2	3.5	2.1	1.2	9.0
West-Southwest	4.4	7.5	3.0	3.4	18.3
East-Southeast	6.1	10.4	5.1	4.0	25.6
Southwest	3.9	5.8	2.0	2.2	13.9
Southeast	3.6	2.8	1.5	2.8	10.7
Northern half of Illinois	10.3	14.8	9.0	6.4	40.5
Southern half of Illinois	11.2	17.5	9.4	7.5	45.6
Entire state	16.2	24.5	15.3	11.4	67.4

and summer probabilities. In summer, for example, there is a 30% probability (given high wind occurs somewhere) that high damaging winds extended over 3200 square miles or more. In winter there is a 10% chance the area of high winds will exceed 9000 square miles. The curves (figure 10) also show the higher likelihood for greater areal extent of high winds in the winter months than in the summer months.

Areal Frequency Distributions

The point data on high wind frequencies were also analyzed to develop regional frequencies for the four seasons for the nine crop reporting districts, for the northern and southern halves of Illinois, and for the entire state. Table 16 shows the seasonal average frequencies of high wind events in each of the areas. The nine crop district values reveal that the maximum incidence is in the East-Southeast District where the annual area average is 25.6 days. The lowest district value is 9.0 days in the East. The seasonal maximum occurs in spring in all areas except the Southeast where the winter average is highest. Lowest seasonal values are in fall in the five districts in the northern half of Illinois and in the ESE district. In the other three southernmost districts, the summer incidences rank as the lowest.

The values for the northern half and southern half of Illinois (table 16) show a higher frequency in the southern half, being higher there in all seasons. The state values show that Illinois has, on the average, 67 days with high winds. Annual values ranged from 130 days to 42 days.

Mesoscale Extent of High Wind Days in Summer

St. Louis Area. Six wind speed recording stations located within a circle of 2000 square miles surrounding St. Louis were operated during the summers (June-August) of 1972-1975 in a study of urban influences on weather (Ackerman etal., 1978). These data were taken on masts with sensors (cup anemometers) at 4 meters above ground. The maximum daily gust values were classed as occurring in three speed classes: ≥ 30 mph, ≥ *40* mph, and ≥ 50 mph.

These daily values became the basis for a limited analysis of the frequency and areal extent of high wind events (days) during summer in a mesoscale area. The six stations in 2000 square miles represent a density of about one station per 333 square miles, much more dense than the 1901-1948 cooperative substation density (~ one per 1300 square miles).

The 4-year point frequencies are shown in figure 11. One notes considerable variability from a low of 7 days to a high of 22 for gust > 30 mph. This is to be expected in a short sampling period of an infrequent event. If one divides the day totals for ≥ 40 mph, shown in figure 11, by 4 years, the resulting summer averages range from 0.3 to 1.7 per

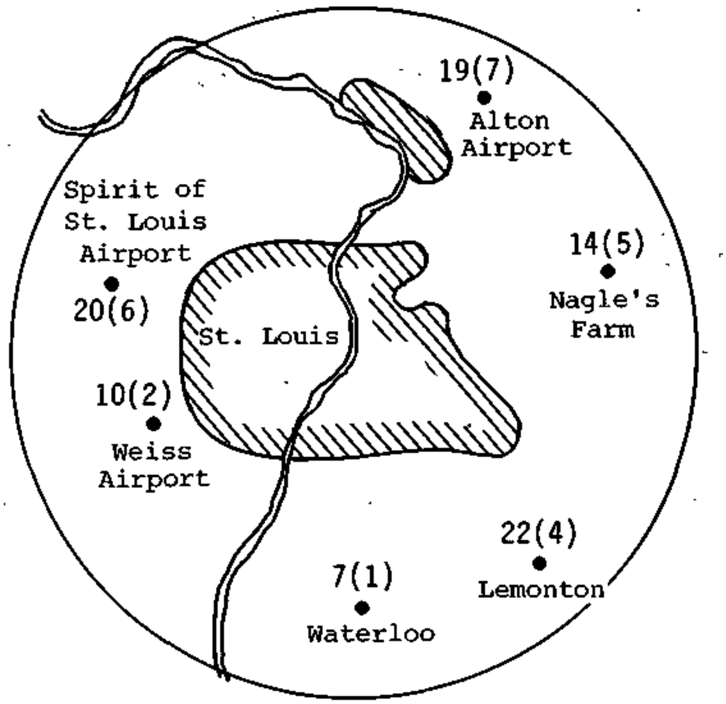

Figure 11. Point frequencies of summer days with gusts exceeding 30 and 40 mph, 1972-1975, in St. Louis area

year. These are generally comparable to the long-term summer averages (figure 4a).

Table 17 presents the frequency of days in each speed category with 53 days (as defined by an occurrence at one or more stations) having ≥ 30 mph gusts. On 27 of these days (51%), only one of the six stations had a ≥ *30* mph gust, and the greatest areal extent occurred on one day when five stations (representing 83% of the area) had > 30 mph gusts. This was with a major squall line that occurred on 18 June 1973.

The frequency and areal extent of gusts ≥ 40 mph, as expected, was much less. Only 21 days in the 2000-square-mile area had ≥ 40 mph gusts in 4 summers (an average of 5 per summer), and the most extensive of these was 4 days when 2 stations had ≥ 40 mph. These results indicate that widespread high gusts in summer are uncommon, which is not unexpected since most high wind occurrences in summer are largely produced by downdrafts of thunderstorms which are seldom uniform and equally strong over a small area. The summer days shown in figure 9 are exceptional events. The typical one-station event (table 17) potentially represents an occurrence over 333 square miles. This compares favorably with rain dimensions of major raincells, 282 square miles (Ackerman et al., 1978). This suggests that many of the summer high wind events (≥ 30 mph) are related to single thunderstorms.

Central Illinois. Further investigation, albeit limited, of the small-scale variations and dimensions of high wind events (≥ 40 mph) was pursued with other data. The Portable Automatic Meteorological (PAM) network, consisting of 27 instruments including wind sensors at 5 meters and speed recorders, was operated during 23 June-29 August 1979 in a 900-square mile area of central Illinois. During this 2-month summer period, wind speeds in excess of 40 mph occurred on five days and all were with thunderstorms. Information on these five events appears in table 18.

Wind speeds were recorded once each minute, and continuous sequences at a point (without al-

Table 17. The Frequency of Stations with High Gusts on Summer (June-August) Days during 1972-1975 in 2000-Square-Mile Area Centered on St. Louis, and Based on 6 Wind Recording Stations

		Number of stations (points) with winds exceeding a given speed level on a day of high gust occurrences				
	Total days	*1 station (16% area)*	*2 stations (33% area)*	*3 stations (50% area)*	*4 stations (66% area)*	*5 stations (83% area)*
When ≥ 30 mph speeds occurred at a point	53	27	16	8	1	1
When ≥ 40 mph speeds occurred at a point	21	17	4	0	0	0
When ≥ 50 mph speeds occurred at a point	4	4	0	0	0	0

Table 18. High Wind Events in Central Illinois PAM Network during Summer 1979

Event date	*Range of time of all events*	*Number of sites ≥ 40 mph*	*Percent of network*	*Areal extent (mi^2)*	*Number of episodes*	*Average point duration (minutes)*	*Range of duration (minutes)*
4 July	0225-0243	4	15	130	10	1.9	1 to 5
6 July	1456-1809	3	11	100	3	1.0	1 to 1
13 July	1513-1556	9	33	300	10	2.0	1 to 6
30 July	1850-1936	12	44	400	15	3.5	1 to 8
18 August	2003-2039	2	8	65	5	2.0	1 to 4
Averages		6	22	200	9	2.4	1 to 8

minute or longer break) were called "episodes." These are illustrated in figure 12 which presents maps of these five events (days). Note for 4 July that there were five episodes at the southwest station; that is, a gust ≥ 40 mph occurred at 0225, followed by 7 minutes without such a gust, then a 4-minute episode (0232-0235), and 1-minuteepisodes at 0237, 0239, and 0242. As shown on table 18, the episodes ranged from 1 up to 8 minutes with an average of 2.4 minutes. In some events, sites with ≥ 40 mph gusts often had two or more episodes, as reflected by the differences in the number of episodes and number of sites for 4 July, 30 July, and 18 August.

The areal extent and number of qualifying sites in each event are shown in table 18. The areal spread in an event never exceeded 44% of the network, and averaged 22%, or 200 square miles. The patterns of high gusts appear in figure 12 a-e. Envelopes (dashed lines) have been drawn around areas where analysis of the gust times indicated coherence and association, typically with motion when two or more sites are together. On 4 July the gusts beginning at 0232 at sites 17 and 24 suggest an eastward motion reaching site 21 at 02 3 5 and site 2 5 at 0242. Long-moving swaths of high wind outbreaks are shown on 30 July associated with a line of thunderstorms. Other events show very isolated outbreaks (6 July and 18 August) with isolated, slow-moving thunderstorms on these days.

These excellent, areally detailed wind data reveal that gusts ≥ 40 mph at a point were often intermittent, occurring for 1 or 2 minutes, then stopping for a few minutes, then reoccurring for 1 or 2 minutes like the 10-year data at Urbana. The typical gust episode duration was 1 to 3 minutes. Their areal outbreaks were either isolated at a point or extended over several points in a traveling swath-like mode that was anywhere from 5 to 15 miles wide and from 5 to 25 miles (or more) long. In a small (900 square miles) fixed network area, the extent of the high wind events is small, typically covering 22% of the area and intermittent over the area.

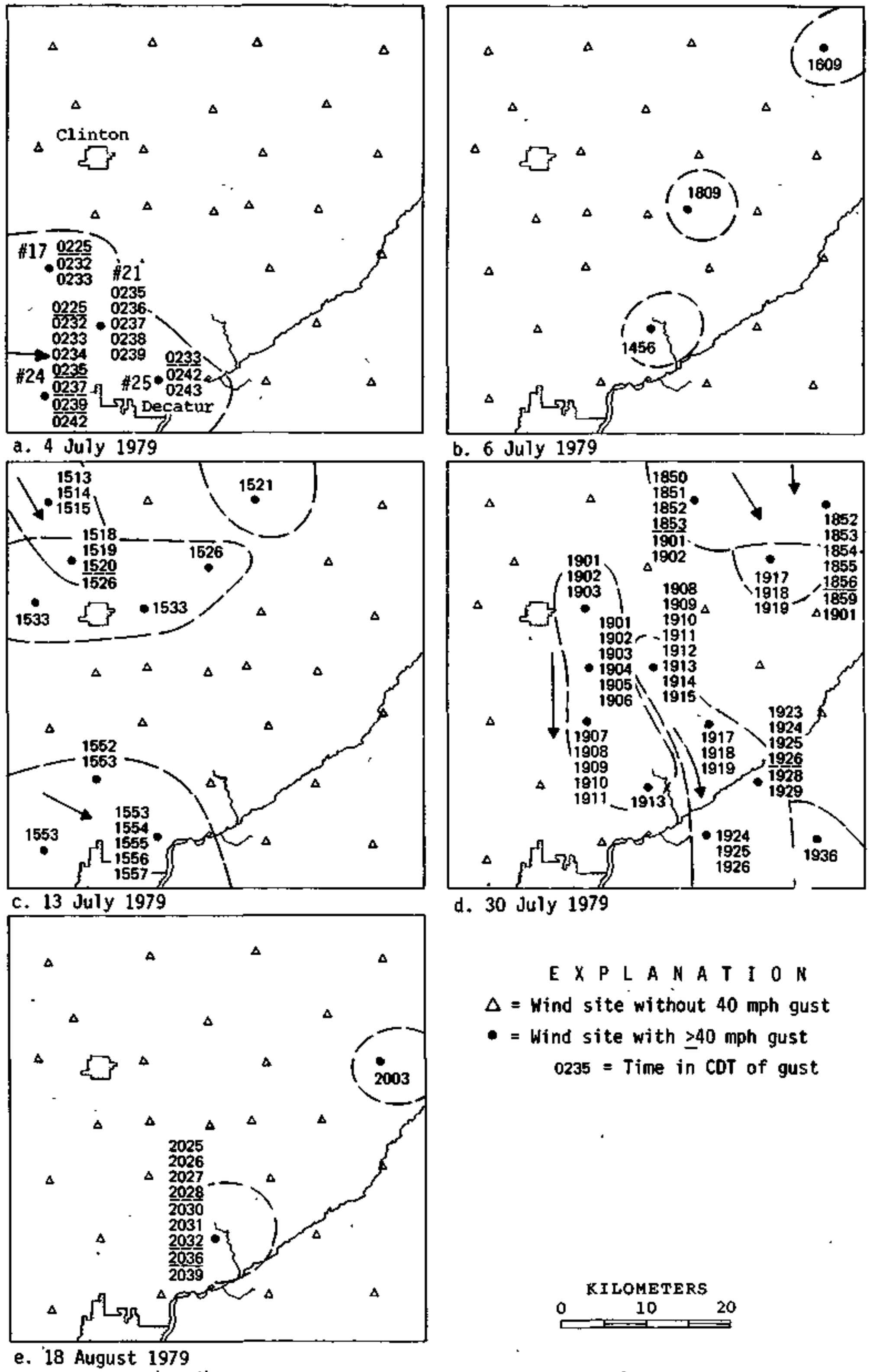

Figure 12. Episodes of wind speeds in excess of 40 mph in wind network on five days in summer 1979

CONCLUSIONS

High winds (≥ 40 or ≥ 45 mph speeds) of a nontornadic origin are a major weather hazard in Illinois. The average annual loss they produce (in 1950-1957 dollars) to property is $3.4 million, which is more property loss than that caused by any other weather hazard. Crop losses from these winds average about $0.4 million per year, the third largest loss value for crops, and high winds are also often an integral part of hail-produced losses. In addition, high winds, on the average, cause 1 death per year. The total property and crop losses cause 23% of all severe weather losses suffered in Illinois. High winds data are also relevant to structural design and to wind energy considerations.

Considering their importance, very little definitive work has been done on the climatology of winds — their areal extent, time and space frequencies, and duration. The lack of study has related to a lack of desired data, i.e., data from many wind sensors operated for many years throughout the state. Only a few recording sensors (less than 10) have been operated continuously in Illinois, and these are too sparse to define most spatial and temporal variations. Historical data on "high (damaging) wind" days as recorded at 43 cooperative substations were used to provide the key data needed. Recent dense wind networks operated in summer weather field studies also provided useful spatial information, and 10-year wind data made at a fast recording speed were used to define the short-term duration characteristics.

The peak season of high winds extends from late winter through spring, the peak months of occurrence being March and April, followed by February, May, and June. High winds are least frequent in August to October. This seasonal distribution reflects the temporal frequency of deep low pressure centers across Illinois.

The average winter season pattern of high wind days is flat except for two high frequency areas, one in southern Illinois and another in NW Illinois, both locales of frequent low centers in winter. The peak season of activity, spring, has two major high frequency areas, extreme southern Illinois (low centers), and the east-west belt across central Illinois (frontal maximum). Summer average pattern of high winds is flat except for a minor high in the northwest fronts and squall lines (and thunderstorms) are most frequent. The fall pattern is flat except for a high frequency area in extreme southern Illinois where low center passages are most frequent. Annually, the state has three maximums: the greatest in extreme southern Illinois, with lesser ones in central Illinois and northwest Illinois.

Thunderstorms occurred with nearly 70% of all high wind point events in summer, but with only 8% of high wind events in winter. This study and the seasonal analysis revealed that most high wind occurrences in Illinois from September through May are a result of deep low center passages, whereas in summer (June-August) thunderstorms are the major producers of high winds.

Summer season high wind occurrences at a point are short-lived, with usually two 1-minute gusts ≥ 40 mph occurring in a 5-minute period. In the other seasons, periods of high winds last much longer, from 2 to 4 hours with several (5 to 10) intermittent gusts of ≥ 40 mph, often separated by lower speed periods of 10 minutes or more. Occurrences of wind ≥ 50 mph are much less frequent and have much shorter duration, typically only 1 minute long. High winds occur most often in the daylight hours.

Extreme winds, based on those expected once in 50 or 100 years, have much higher speeds in northern Illinois than in central and southern Illinois. For example, the 50-year point value in NW Illinois is 110 mph compared with 65 mph in southern Illinois. Thus, although high wind events are most frequent in southern Illinois, the highest values occur in the northern third of the state.

The six days with the most extensive high wind occurrences in winter (colder half year) had high winds over 50% or more of Illinois. The six most extensive high wind days in the warm season had lesser coverage but tended to reflect multi-county outbreaks, either inside or just east of areas of thunderstorms. The daily areal extent of high winds are greatest in the November-May period, but 60% of all days with high winds are based on an occurrence at only one station.

The southern half of the state has, on the average, 46 days a year with high winds, and the northern half of Illinois has 41 days. The state experiences an average of 67 days of high winds per year.

Mesoscale networks (900 to 2000 square miles) operated in Illinois in recent summers reveal that high wind outbreaks were all thunderstorm related and typically of very limited extent, covering 22% of the areas when they occurred. Their point durations were short, 1 to 3 minutes. Their areal patterns were either very isolated point events or outbreaks in swaths that were 5 to 15 miles wide and 10 to 25 miles long.

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APPENDIX

Material abstracted from a 1979 report (Simiu et al.) is presented in this Appendix to provide recent tabular data on extreme wind speeds at selected airport stations at which reliable wind records are available over a number of consecutive years. The data came from extreme yearly wind speeds, and the corresponding wind directions. Most were the originally recorded data of fastest-mile speeds. These have been listed without modification from the report. However, at a few stations, some of the recorded data consisted of fastest observed 1-minute speeds, which were transformed into fastest-mile speeds by a relation given in the report. These fastest-mile speeds were listed in the NBS report.

Statistical analysis of the wind speed data included the predicted wind speeds corresponding to various return periods, based on the assumption that the Type I probability distribution of the largest values is a valid description of the extreme wind speeds. Extreme wind speed predictions were included for mean recurrence intervals of up to 1,000,000 years. However, in the authors' opinion, physical considerations suggested that predictions corresponding to mean recurrence intervals beyond a few hundred years should be regarded with caution.

The original data consisted of fastest-mile wind speeds, i.e., speeds averaged over a time interval (in seconds) t = 3600/vr, and V_f = the fastest-mile wind speed in miles per hour. In an attempt to ensure that the terrain roughness conditions were uniform among all the sets of data analyzed, only airport stations were considered. In principle, it may be assumed that at such stations open exposure conditions prevail. Nevertheless, the mere fact that wind speed measurements are taken at an airport station does not ensure that the wind conditions reflected by these measurements are identical, from the standpoint of the terrain exposure, to those prevailing at a different airport. For example, the estimated 50-year wind at Chicago Midway Airport is about 15 mph less than that at the Chicago O'Hare Airport. The probable reason for this difference is that the terrain around the Chicago Midway Airport is relatively heavily built-up.

To ensure the homogeneity of the values at any given station, all the wind speeds were reduced to a common elevation. The elevation chosen for this purpose was 10 m above ground.

The mean wind profile near the ground in homogeneous terrain is given by the well-known logarithmic law, which may be written in the form:

$$U(z)= [\ln(z/z_O)/\ln(10/z_O)]U(10)$$

where z = height above ground and z_O = roughness length, both expressed in meters. In open terrain, z_O may vary from, say, 0.03 m to 0.10 m. In their report the reduction of the data to an elevation of 10 m was based on the assumption z_O = 0.05 m.

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CHICAGO MIDWAY ILLINOIS (1943-1977)

THE SAMPLE NUMBER OF OBSERVATIONS	=	35.00
THE SAMPLE MEAN	=	47.02
THE SAMPLE STANDARD DEVIATION	=	4.77
THE SAMPLE MINIMUM	=	37.42
THE SAMPLE MAXIMUM	=	58.57

DATE	ANEMOMETER ELEVATION(FT)	FASTEST MILE WIND SPEED AND DIRECTION (RECORDED AT ANEMOMETER ELEVATION)		CALCULATED FASTEST MILE WIND SPEED AT 10M ABOVE GROUND (CORRECTED SPEED)
04/27/43	36.	45.	SW	44.
05/25/44	36.	47.	S	46.
03/17/45	36.	42.	W	41.
11/21/46	36.	38.	W	37.
09/22/47	36.	47.	N	46.
12/05/48	36.	50.	SW	49.
08/31/49	38.	54.	NW	53.
05/05/50	38.	54.	S	53.
04/28/51	38.	50.	NW	49.
11/26/52	38.	60.	SW	59.
06/04/53	38.	50.	W	49.
03/25/54	38.	51.	W	50.
03/22/55	38.	54.	NW	53.
03/10/56	38.	46.	SW	45.
03/15/57	38.	43.	W	42.
11/17/58	48.	49.	SW	46.
05/28/59	48.	51.	W	48.
03/22/60	48.	42.	NW	40.
03/27/61	48.	47.	SW	44.
04/09/62	48.	45.	W	42.
06/08/63	20.	49.	N	54.
05/08/64	20.	47.	SW	51.
12/24/65	20.	47.	NE	51.
07/18/66	20.	39.	W	43.
02/15/67	20.	51.	SW	56.
11/28/68	20.	42.	NE	46.
04/21/69	20.	38.	W	42.
07/02/70	20.	39.	NW	43.
11/01/71	20.	43.	S	47.
01/24/72	20.	40.	SW	44.
04/19/73	20.	42.	SE	46.
07/14/74	20.	41.	W	45.
11/30/75	20.	43.	S	47.
06/13/76	20.	40.	E	44.
03/29/77	20.	47.	S	51.

CHICAGO MIDWAY ILLINOIS (1943-1977)

RETURN PERIOD (IN YEARS)	PREDICTED EXTREME WIND BASED ON EXTREME VALUE TYPE 1 DISTRIBUTION	ESTIMATED STAN. DEV. SAMPL. ERROR CRAMER-RAO	ESTIMATED STAN. DEV. SAMPL. ERROR METH. OF MOM.
2.0	46.28	.74	.74
3.0	48.37	.90	.94
4.0	49.71	1.03	1.11
5.0	50.70	1.13	1.25
6.0	51.49	1.22	1.36
7.0	52.15	1.29	1.46
8.0	52.71	1.35	1.54
9.0	53.20	1.40	1.62
10.0	53.63	1.45	1.68
20.0	56.44	1.78	2.13
30.0	58.06	1.97	2.39
35.0	58.67	2.04	2.49
40.0	59.20	2.11	2.57
50.0	60.08	2.21	2.72
60.0	60.80	2.30	2.83
70.0	61.40	2.37	2.93
80.0	61.93	2.44	3.02
90.0	62.39	2.49	3.10
100.0	62.80	2.54	3.17
200.0	65.52	2.87	3.61
300.0	67.11	3.07	3.88
400.0	68.23	3.21	4.07
500.0	69.10	3.31	4.21
600.0	69.82	3.40	4.33
700.0	70.42	3.48	4.43
800.0	70.94	3.54	4.52
900.0	71.40	3.60	4.59
1000.0	71.81	3.65	4.66
2000.0	74.52	3.98	5.12
3000.0	76.10	4.18	5.38
4000.0	77.22	4.32	5.57
5000.0	78.10	4.43	5.72
6000.0	78.81	4.52	5.84
7000.0	79.41	4.59	5.94
8000.0	79.93	4.66	6.02
9000.0	80.39	4.71	6.10
10000.0	80.80	4.77	6.17
50000.0	87.09	5.55	7.23
100000.0	89.79	5.89	7.68
500000.0	96.08	6.67	8.74
1000000.0	98.79	7.01	9.20

MOLINE ILLINOIS (1944-1977). REFER TO SECT. 2.2

THE SAMPLE NUMBER OF OBSERVATIONS	=	34.00
THE SAMPLE MEAN	=	54.78
THE SAMPLE STANDARD DEVIATION	=	7.73
THE SAMPLE MINIMUM	=	39.81
THE SAMPLE MAXIMUM	=	72.08

DATE	ANEMOMETER ELEVATION(FT)	FASTEST MILE WIND SPEED AND DIRECTION (RECORDED AT ANEMOMETER ELEVATION)	CALCULATED FASTEST MILE WIND SPEED AT 10M ABOVE GROUND (CORRECTED SPEED)
05/03/44	50.	56. SW	52.
04/11/45	50.	70. SW	66.
08/09/46	50.	56. SW	52.
06/10/47	50.	77. SW	72.
12/05/48	50.	60. SW	56.
10/10/49	50.	56. SW	52.
05/05/50	54.	65. SW	60.
05/19/51	54.	57. SW	53.
03/23/52	54.	61. SW	56.
03/22/53	54.	66. S	61.
03/25/54	54.	66. SW	61.
05/06/55	54.	68. SW	63.
04/03/56	54.	69. SW	64.
03/15/57	54.	54. SW	50.
05/22/58	54.	43. W	40.
03/15/59	25.	45. NW	47.
02/10/60	25.	45. NE	47.
09/01/61	25.	44. SW	46.
11/23/62	25.	45. NW	47.
07/19/63	25.	59. NW	62.
05/08/64	25.	52. SW	55.
11/27/65	25.	46. W	48.
05/07/66	25.	63. NE	66.
05/18/67	25.	50. NW	52.
12/05/68	25.	44. NW	46.
07/03/69	25.	43. SW	45.
05/09/70	25.	56. SW	59.
04/27/71	25.	47. E	49.
07/14/72	25.	49. W	51.
06/18/73	25.	57. SE	60.
06/20/74	25.	57. N	60.
12/14/75	25.	43. SW	45.
06/13/76	25.	64. NW	67.
07/10/77	25.	47. SE	49.

MOLINE,ILLINOIS (1944-1977).

RETURN PERIOD (IN YEARS)	PREDICTED EXTREME WIND BASED ON EXTREME VALUE TYPE 1 DISTRIBUTION	ESTIMATED STAN. DEV. SAMPL. ERROR CRAMER-RAO	ESTIMATED STAN. DEV. SAMPL. ERROR METH. OF MOM.
2.0	53.59	1.21	1.22
3.0	56.96	1.49	1.55
4.0	59.11	1.70	1.82
5.0	60.71	1.86	2.05
6.0	61.98	2.00	2.24
7.0	63.03	2.12	2.40
8.0	63.93	2.22	2.53
9.0	64.72	2.31	2.66
10.0	65.42	2.39	2.77
20.0	69.94	2.92	3.50
30.0	72.54	3.24	3.92
34.0	73.34	3.34	4.06
40.0	74.38	3.46	4.23
50.0	75.79	3.64	4.47
60.0	76.-95	3.78	4.66
70.0	77.93	3.90	4.82
80.0	78.77	4.00	4.96
90.0	79.51	4.10	5.09
100.0	80.18	4.18	5.20
200.0	84.55	4.72	5.94
300.0	87.10	5.04	6.37
400.0	88.91	5.27	6.68
500.0	90.31	5.45	6.92
600.0	91.46	5.59	7.12
700.0	92.43	5.71	7.28
800.0	93.27	5.82	7.42
900.0	94.01	5.91	7.55
1000.0	94.67	6.00	7.66
2000.0	99.03	6.55	8.41
3000.0	101.57	6.87	8.84
4000.0	103.38	7.10	9.15
5000.0	104.78	7.28	9.39
6000.0	105.93	7.42	9.59
7000.0	106.90	7.55	9.76
8000.0	107.73	7.65	9.90
9000.0	108.47	7.75	10.03
10000.0	109.14	7.83	10.14
50000.0	119.25	9.12	11.88
100000.0	123.60	9.68	12.63
500000.0	133.72	10.97	14.37
1000000.0	138.07	11.52	15.12

PEORIA ILLINOIS (1943-1977)

THE SAMPLE NUMBER OF OBSERVATIONS = 35.00
THE SAMPLE MEAN = 53.04
THE SAMPLE STANDARD DEVIATION = 6.96
THE SAMPLE MINIMUM = 40.50
THE SAMPLE MAXIMUM = 70.21

DATE	ANEMOMETER ELEVATION(FT)	FASTEST MILE WIND SPEED AND DIRECTION (RECORDED AT ANEMOMETER ELEVATION)		CALCULATED FASTEST MILE WIND SPEED AT 10M ABOVE GROUND (CORRECTED SPEED)
07/28/43	26.	60.	NW	63.
04/11/44	26.	50.	E	52.
11/08/45	26.	50.	SW	52.
06/12/46	26.	50.	W	52.
04/05/47	26.	66.	SW	69.
12/05/48	50.	58.	SW	54.
01/27/49	50.	52.	W	49.
05/05/50	50.	61.	SW	57.
09/26/51	50.	50.	W	47.
11/26/52	50.	50.	SW	47.
07/05/53	50.	75.	NW	70.
05/31/54	50.	55.	SW	51.
03/22/55	50.	50.	NW	47.
08/13/56	50.	65.	W	61.
03/14/57	50.	52.	SW	49.
10/09/58	50.	60.	SW	56.
09/26/59	50.	60.	W	56.
05/24/60	20.	47.	NW	51.
03/27/61	20.	43.	SW	47.
04/30/62	20.	40.	W	44.
07/19/63	20.	41.	NW	45.
11/20/64	20.	56.	W	61.
09/14/65	20.	51.	W	56.
03/31/66	20.	40.	NW	44.
02/23/67	20.	46.	NW	50.
12/04/68	20.	39.	NW	43.
06/25/69	20.	43.	W	47.
05/13/70	20.	44.	NE	48.
12/15/71	20.	46.	SW	50.
01/24/72	20.	37.	W	41.
06/16/73	20.	54.	NW	59.
07/14/74	20.	49.	W	54.
07/23/75	20.	50.	W	55.
03/04/76	20.	43.	W	47.
03/30/77	20.	44.	SW	48.

PEORIA. ILLINOIS (1943-1977)

RETURN PERIOD <IN YEARS)	PREDICTED EXTREME WIND BASED ON OPTIMAL EXTREME VALUE TYPE 2, DISTRIBUTION (GAMMA = 350.00000)	PREDICTEO EXTREME WIND BASED ON EXTREME VALUE TYPE 1 DISTRIBUTION	ESTIMATED STAN. DEV. SAMPL. ERROR CRAMER-RAO	ESTIMATED STAN. DEV. SAMPL. ERROR METH. OF MOM.
2.0	50.95	50.96	1.08	1.08
3.0	54.01	54.03	1.32	1.37
4.0	55.98	55.99	1.50	1.62
5.0	57.44	57.45	1.65	1.82
6.0	58.60	58.61	1.77	1.98
7.0	59.56	59.57	1.88	2.13
8.0	60.39	60.39	1.97	2.25
9.0	61.11	61.11	2.05	2.36
10.0	61.75	61.75	2.12	2.46
20.0	65.89	65.87	2.59	3.10
30.0	68.28	68.24	2.87	3.48
35.0	69.18	69.14	2.98	3.63
40.0	69.96	69.92	3.07	3.75
50.0	71.26	71.21	3.23	3.96
60.0	72.33	72.26	3.35	4.13
70.0	73.23	73.15	3.46	4.28
80.0	74.00	73.92	3.55	4.40
90.0	74.69	74.60	3.63	4.52
100.0	75.30	75.21	3.71	4.61
200.0	79.33	79.20	4.19	5.27
300.0	81.69	81.52	4.47	5.65
400.0	83.36	83.17	4.68	5.93
500.0	84.66	84.45	4.83	6.14
600.0	85.72	85.50	4.96	6.31
700.0	86.62	86.38	5.07	6.46
800.0	87.40	87.15	5.16	6.59
900.0	88.08	87.82	5.25	6.70
1000.0	88.70	88.43	5.32	6.80
2000.0	92.74	92.40	5.81	7.46
3000.0	95.11	94.72	6.10	7.85
4000.0	96.79	96.37	6.30	8.12
5000.0	98.10	97.65	6.46	8.33
6000.0	99.17	98.69	6.59	3.51
7000.0	100.07	99.58	6.70	8.66
8000.0	100.85	100.34	6.79	8.78
9000.0	101.54	101.02	6.87	8.90
10000.0	102.16	101.62	6.95	9.00
50000.0	111.62	110.84	8.09	10.54
100000.0	115.71	114.81	8.58	11.20
500000.0	125.24	124.04	9.73	12.74
1000000.0	129.36	128.01	10.22	13.41

SPRINGFIELD, ILLINOIS (1948- 1977)

THE SAMPLE NUMBER OF OBSERVATIONS	=	30.00
THE SAMPLE MEAN	=	54.15
THE SAMPLE STANDARD DEVIATION	=	5.96
THE SAMPLE MINIMUM	=	45.97
THE SAMPLE MAXIMUM	=	70.63

DATE	ANEMOMETER ELEVATION(FT)	FASTEST MILE WIND SPEED AND DIRECTION (RECORDED AT ANEMOMETER ELEVATION)	CALCULATED FASTEST MILE WIND SPEED AT 10M ABOVE GROUND (CORRECTED SPEED)
12/06/48	48.	66. SW	62.
01/27/49	48.	65. SW	61.
05/05/50	48.	57. SW	54.
08/15/51	48.	58. W	55.
03/23/52	48.	59. W	56.
12/14/53	48.	58. W	55.
08/18/54	48.	50. W	47.
05/26/55	48.	56. SW	53.
06/26/56	48.	54. SW	51.
06/14/57	48.	75. SW	71.
05/31/58	48.	51. N	48.
03/06/59	48.	57. W	54.
05/25/60	48.	58. W	55.
03/27/61	48.	65. SW	61.
07/13/62	48.	73. SW	69.
06/10/63	20.	49. NW	54.
06/21/64	20.	48. W	53.
03/17/65	20.	45. W	49.
03/23/66	20.	42. W	46.
01/06/67	20.	51. SW	56.
12/22/68	20.	42. SW	46.
06/28/69	20.	48. NW	53.
06/14/70	20.	50. NE	55.
12/15/71	20.	54. SW	59.
01/24/72	20.	45. W	49.
04/20/73	20.	45. SE	49.
05/30/74	20.	48. NE	53.
11/29/75	20.	49. SW	54.
03/12/76	20.	48. SW	53.
04/02/77	20.	44. W	48.

SPRINGFIELD, ILLINOIS (1948- 1977)

RETURN PERIOD <IN YEARS)	PREDICTED EXTREME WIND BASED ON EXTREME VALUE TYPE 1 DISTRIBUTION	PREDICTED EXTREME WIND BASED ON OPTIMAL EXTREME VALUE TYPE 2. DISTRIBUTION (GAMMA = 9.00000)	ESTIMATED STAN. DEV. SAMPL. ERROR CRAMER-RAO	ESTIMATED STAN. DEV. SAMPL. ERROR METH. OF MOM.
2.0	53.23	52.93	1.00	1.00
3.0	55.85	55.42	1.22	1.27
4.0	57.52	57.09	1.39	1.50
5.0	58.76	58.37	1.53	1.68
6.0	59.75	59.42	1.64	1.84
7.0	60.57	60.30	1.74	1.97
8.0	61.27	61.07	1.82	2.08
9.0	61.88	61.76	1.90	2.18
10.0	62.42	62.37	1.96	2.27
20.0	65.93	66.54	2.40	2.87
30.0	67.95	69.09	2.66	3.22
30.0	67.95	69.09	2.66	3.22
40.0	69.38	70.96	2.84	3.48
50.0	70.48	72.45	2.99	3.67
60.0	71.37	73.69	3.10	3.83
70.0	72.13	74.75	3.20	3.96
80.0	72.79	75.69	3.29	4.08
90.0	73.37	76.53	3.37	4.18
100.0	73.88	77.29	3.43	4.27
200.0	77.28	82.51	3.88	4.88
300.0	79.26	85.75	4.14	5.24
400.0	80.66	88.14	4.33	5.49
500.0	81.75	90.04	4.48	5.69
600.0	82.64	91.63	4.60	5.85
700.0	83.39	93.00	4.70	5.98
800.0	84.05	94.21	4.78	6.10
900.0	84.62	95.29	4.86	6.20
1000.0	85.13	96.27	4.93	6.30
2000.0	88.52	102.99	5.38	6.91
3000.0	90.49	107.16	5.65	7.27
4000.0	91.90	110.24	5.83	7.52
5000.0	92.99	112.70	5.98	7.72
6000.0	93.88	114.75	6.10	7.88
7000.0	94.63	116.52	6.20	8.02
8000.0	95.28	118.08	6.29	8.14
9000.0	95.85	119.47	6.37	8.24
10000.0	96.37	120.74	6.44	8.33
50000.0	104.22	141.96	7.49	9.76
100000.0	107.60	152.33	7.95	10.37
500000.0	115.45	179.77	9.01	11.80
1000000.0	118.83	193.17	9.47	12.42

EVANSVILLE. INDIANA (1941-1977)

THE SAMPLE NUMBER OF OBSERVATIONS = 37.00
THE SAMPLE MEAN = 46.65
THE SAMPLE STANDARD OEVIATION = 6.11
THE SAMPLE MINIMUM = 36.12
THE SAMPLE MAXIMUM = 61.30

DATE	ANEMOMETER ELEVATION(FT)	FASTEST MILE WIND SPEED AND DIRECTION (RECORDED AT ANEMOMETER ELEVATION)		CALCULATED FASTEST MILE WIND SPEED AT 10M ABOVE GROUND (CORRECTED SPEED)
07/07/41	40.	53.	NW	51.
06/11/42	40.	SO.	S	48.
08/04/43	40.	49.	SW	47.
03/04/44	40.	54.	W	52.
03/17/45	40.	56.	S	54.
02/13/46	40.	52.	SW	50.
03/24/47	40.	50.	W	48.
03/19/48	40.	54.	SW	52.
06/24/49	40.	56.	S	54.
11/20/50	40.	40.	SW	39.
05/27/51	64.	45.	NW	41.
06/30/52	64.	47.	NW	43.
04/30/53	64.	49.	SE	44.
02/20/54	64.	54.	SE	49.
03/01/55	64.	47.	SW	43.
02/25/56	64.	59.	W	53.
06/12/57	64.	57.	NW	52.
06/10/58	64.	58.	NW	52.
03/05/59	64.	53.	SE	48.
05/24/60	64.	42.	NW	38.
05/07/61	64.	47.	NW	43.
04/-30/62	20.	43.	SW	47.
08/28/63	20.	49.	NW	54.
03/04/64	20.	43.	S	47.
05/18/65	20.	42.	NW	46.
07/06/66	20.	38.	NW	42.
02/15/67	20.	39.	W	43.
11/28/68	20.	36.	S	39.
05/10/69	20.	35.	W	38.
04/19/70	20.	34.	SW	37.
12/10/71	20.	56.	SW	61.
07/15/72	20.	33.	SW	36.
01/26/74	20.	41.	S	45.
04/07/74	20.	34.	SW	37.
05/25/75	20.	49.	SW	54.
01/13/76	20.	43.	W	47.
06/30/77	20.	46.	W	50.

EVANSVIULE.INDIANA (1941-1977)

RETURN PERIOD (IN YEARS)	PREDICTED EXTREME WIND BASED ON EXTREME VALUE TYPE 1 DISTRIBUTION	ESTIMATED STAN. DEV. SAMPL. ERROR CRAMER-RAO	ESTIMATED STAN. DEV. SAMPL. ERROR METH. OF MOM.
2.0	45.73	.92	.92
3.0	48.33	1.13	1.17
4.0	50.00	1.28	1.38
5.0	51.23	1.41	1.55
6.0	52.21	1.51	1.69
7.0	53.03	1.60	1.81
8.0	53.72	1.68	1.92
9.0	54.33	1.75	2.01
10.0	54.87	1.81	2.10
20.0	58.37	2.21	2.65
30.0	60.38	2.45	2.97
37.0	61.41	2.58	3.14
40.0	61.80	2.62	3.20
50.0	62.89	2.75	3.38
60.0	63.79	2.86	3.53
70.0	64.54	2.95	3.65
80.0	65.19	3.03	3.76
90.0	65.77	3.10	3.86
100.0	66.28	3.16	3.94
200.0	69.66	3.58	4.50
300.0	71.63	3.82	4.83
400.0	73.03	3.99	5.06
500.0	74.12	4.13	5.24
600.0	75.00	4.24	5.39
700.0	75.75	4.33	5.51
800.0	76.40	4.41	5.62
900.0	76.97	4.48	5.72
1000.0	77.48	4.54	5.80
2000.0	80.85	4.96	6.37
3000.0	82.82	5.20	6.70
4000.0	84.22	5.38	6.93
5000.0	85.30	5.51	7.12
6000.0	86.19	5.62	7.26
7000.0	86.94	5.72	7.39
8000.0	87.58	5.80	7.50
9000.0	88.16	5.87	7.59
10000.0	88.67	5.93	7.68
50000.0	96.48	6.91	9.00
100000.0	99.85	7.33	9.56
500000.0	107.67	8.31	10.88
1000000.0	111.03	8.73	11.45

ST.LOUIS.MISSOURI (1959-1977)

THE SAMPLE NUMBER OF OBSERVATIONS	=	19.00
THE SAMPLE MEAN	=	47.39
THE SAMPLE STANDARD DEVIATION	=	7.39
THE SAMPLE MINIMUM	=	33.37
THE SAMPLE MAXIMUM	=	65.68

DATE	ANEMOMETER ELEVATION(FT)	FASTEST MILE WIND SPEED AND DIRECTION CRECORDED AT ANEMOMETER ELEVATION)	CALCULATED FASTEST MILE WIND SPEED AT 10M ABOVE GROUND (CORRECTED SPEED)
03/15/59	82.	38. W	33.
04/01/60	82.	55. S	48.
11/02/61	82.	41. S	36.
08/03/62	20.	38. S	42.
06/03/63	20.	45. W	49.
06/29/64	20.	60. SE	66.
08/27/65	20.	54. NW	59.
08/15/66	20.	48. NW	53 .
10/24/67	20.	45. SW	49.
03/12/68	20.	42. NE	46.
10/10/69	20.	45. SW	49.
05/29/70	20.	42. SE	46.
12/15/71	20.	42. SW	46.
02/18/72	20.	40. NW	44.
06/18/73	20.	43. N	47.
06/09/74	20.	50. SW	55.
08/25/75	20.	41. NW	45.
03/12/76	20.	38. SW	42.
05/04/77	20.	42. SW	46.

ST.LOUIS.MISSOURI (1959-1977)

RETURN PERIOD (IN YEARS)	PREDICTED EXTREME WIND BASED ON EXTREME VALUE TYPE 1 DISTRIBUTION	ESTIMATED STAN. DEV. SAMPL. ERROR CRAMER-RAO	ESTIMATED STAN. DEV. SAMPL. ERROR METH. OF MOM.
2.0	46.29	1.55	1.56
3.0	49.59	1.90	1.93
4.0	51.70	2.17	2.34
5.0	53.27	2.38	2.62
6.0	54.51	2.56	2.86
7.0	55.54	2.71	3.07
8.0	56.43	2.84	3.24
9.0	57.20	2.96	3.40
10.0	57.88	3.06	3.54
19.0	61.99	3.69	4.41
20.0	62.31	3.74	4.48
30.0	64.86	4.14	5.02
40.0	66.66	4.43	5.41
50.0	68.05	4.65	5.72
60.0	69.18	4.84	5.96
70.0	70.13	4.99	6.17
80.0	70.96	5.12	6.36
90.0	71.69	5.24	6.52
100.0	72.34	5.35	6.66
200.0	76.62	6.05	7.61
300.0	79.12	6.46	8.16
400.0	80.89	6.75	8.55
500.0	82.27	6.97	8.86
600.0	83.39	7.16	9.11
700.0	84.34	7.32	9.32
800.0	85.16	7.45	9.50
900.0	85.89	7.57	9.67
1000.0	86.54	7.68	9.81
2000.0	90.80	8.38	10.76
3000.0	93.30	8.80	11.32
4000.0	95.07	9.09	11.72
5000.0	96.44	9.32	12.03
6000.0	97.56	9.50	12.28
7000.0	98.51	9.66	12.49
8000.0	99.33	9.80	12.67
9000.0	100.06	9.92	12.84
10000.0	100.71	10.03	12.98
50000.0	110.61	11.67	15.20
100000.0	114.87	12.39	16.16
500000.0	124.79	14.04	18.39
1000000.0	129.05	14.75	19.35