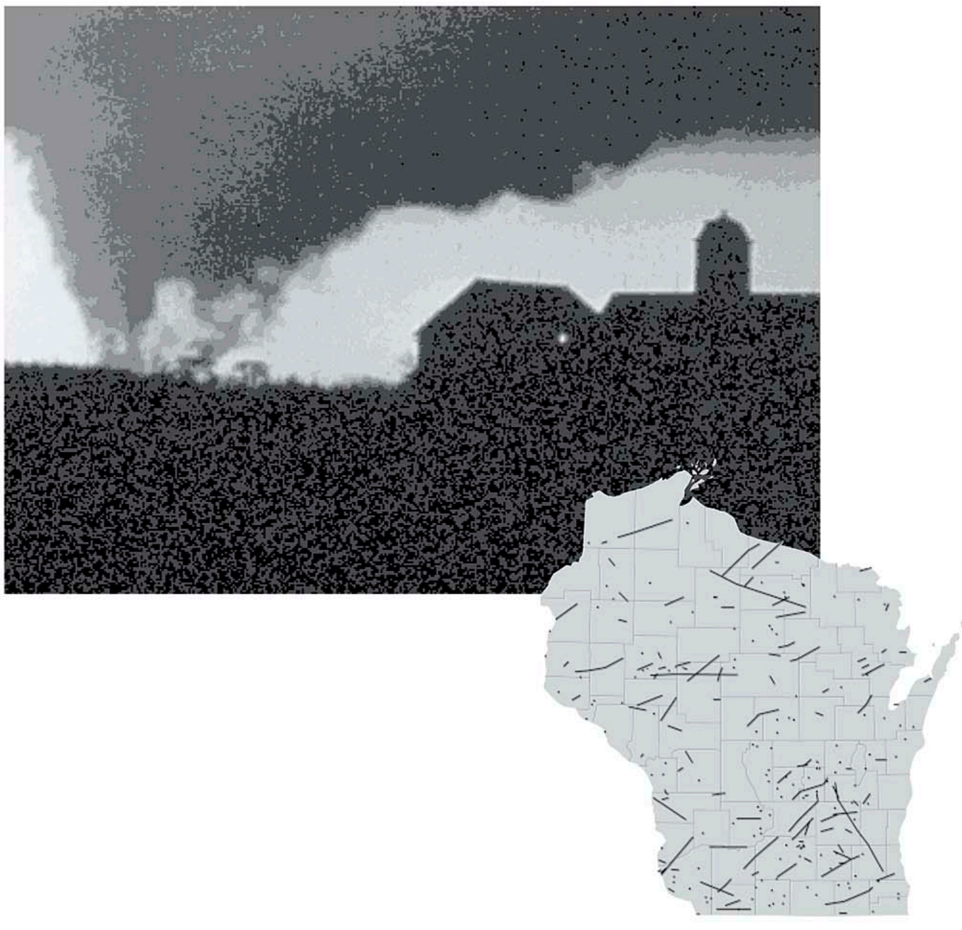
A TORNADO CLIMATOLOGY FOR WISCONSIN



Pamela Naber Knox
Douglas G. Norgord

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY
BULLETIN 100 ◆ 2000

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The Survey conducts earth-science surveys, field studies, and research. We provide objective scientific information about the geology, mineral resources, water resources, soil, climate, and biology of Wisconsin. We collect, interpret, disseminate, and archive natural resource information. We communicate the results of our activities through publications, technical talks, and responses to inquiries from the public. These activities support informed decision-making by government, industry, business, and individual citizens of Wisconsin.

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The Wisconsin Geological and Natural History Survey also maintains collaborative relationships with a number of local, state, regional, and federal agencies and organizations regarding educational outreach and a broad range of natural resource issues.

FIGURES

TABLES

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We thank Daniel Leathers, Delaware State Climatologist, Paul Waite, retired Iowa State Climatologist, and Rusty Kapela and Margaret Mooney, National Weather Service, for their helpful reviews. We especially thank Rusty for providing copies of his photographs of the Oshkosh tornado of 1974.

ABOUT THE AUTHORS

Pamela Naber Knox was the Wisconsin State Climatologist from 1989 to 1998; the data that this book is based upon were tabulated and analyzed during that time. She is presently an adjunct professor of physics and meteorology at Valparaiso University in Valparaiso, Indiana; she also does private meteorological consulting for lawyers and engineers. Douglas Norgord is a former employee of the State Climatology Office and has continued his interest in tornadoes by conducting his own research. He is now a senior computer-aided design specialist at TDS TELECOM in Madison, Wisconsin, and is president and owner of Geographic Techniques, also in Madison.

INTRODUCTION

Tornadoes hold a special fascination for weather watchers of all ages. Many people become interested in tornadoes for the first time when a tornado affects them personally, either by causing damage to property or when seeing one in person. In fact, many meteorologists first became interested in studying the weather professionally after experiencing a tornado or other severe weather at an early age. Other people are naturally curious about the weather that affects their region or state or are intrigued by pictures shown of tornadoes in other parts of the country. Local historians are also interested in the great events that have shaped their communities.

In addition to learning how severe weather affects history, people also study tornadoes to discover how to protect lives and properties from severe weather. Schools want to protect children from the dangers of high winds, hail, and shattered school buildings. Engineers want to identify the maximum wind stress their buildings may have to withstand.

Because of the widespread interest in tornadoes, we have compiled this atlas to describe the general climatological characteristics of tornadoes in Wisconsin. It is intended as an overview of when and where Wisconsin tornadoes occur and why they form. Because tornadoes are only one kind of severe weather that can affect Wisconsin residents, we also take a brief look at other types of severe weather. Then we present a series of maps to provide insight into where tornadoes have historically touched down over space and time across the state. At the end of the document, we have included tornado safety rules and a bibliography of references and additional material on tornadoes.

A map of Wisconsin's counties is provided on the inside back cover.

TYPICAL CONDITIONS ASSOCIATED WITH WISCONSIN TORNADOES

Tornado climatology provides a description of where and when tornadoes form. Tornado occurrence depends not only on the large-scale features of the land, but also on how tornadic storms develop under certain types of weather conditions. Much of the following introductory material describing some of the factors in tornado formation is based on information from Grazulis (1993).

CLIMATOLOGICAL CONDITIONS

Although tornadoes have been seen in many countries of the world, well over half of them—and most of the intense ones—form in the United States. The unique geographic combination of the high Rocky Mountain range on the west and the warm Gulf of Mexico to the south provides perfect conditions for the development of severe weather. Although the majority of tornadoes touch down in the eastern two-thirds of the country, tornadoes have been observed in every state. The only states that average less than one tornado per year are Alaska (because of its northern location) and Rhode Island (because of its small size).

Generally, most tornadoes form in the region known as "Tornado Alley," located in Texas, Oklahoma, Kansas, and the Central Plains, south and west of Wisconsin. In Tornado Alley, more than seven tornadoes are observed within a 10,000-square-mile area every year. (Tornado statistics are standardized by area because state and county sizes are so varied across the country.) Smaller areas of high tornado probability are located in Indiana and Florida; weak tornadoes are also observed in California. However, tornadoes in Florida and California in particular are more likely to be small and of short duration and do not provide as much risk of injury or damage as tornadoes in Mississippi, South Dakota, or other states with lower frequency of occurrence. In Wisconsin, the average annual number of tornadoes per 10,000 square miles ranges from more than five per year in south-central Wisconsin to less than one per year near Ashland; the average number for the state is 3.3 tornadoes per 10,000 square miles per year.

Climatologically, tornadoes tend to develop in regions where there are strong contrasts in temperature and humidity across short distances. The collision of distinct air masses and the high winds that lie above the *front* or boundary between these air masses provides the energy needed to foster the development of intense thunderstorms, in which tornadoes, hail, and damaging winds are most likely to happen. Because the strongest temperature and humidity contrasts move with the season, the regions in which tornadoes form also change from south to north in spring and back toward the south in late summer and fall. As a result, Wisconsin has only had one tornado in January and none in February because most tornado activity is restricted to the states bordering the Gulf of Mexico at that time. Tornado activity reaches its peak in the northern United States in June and July, when temperature gradients are strongest near the Canadian border. (Maps of Wisconsin tornadoes by month are in the section *Characteristics of tornado climatology—Spatial distribution of tornadoes, by month.*)

Lake Michigan also affects the development of tornadoes climatologically. Because the lake is cold in spring in relation to the land nearby, the lake stabilizes the atmosphere near it, suppressing the formation of deep thunderstorm convection. (Lake Superior also has this effect, although tornadoes in northern Wisconsin are less likely because of cool conditions even away from the lake.) This leads to a reduction in the number of tornadoes that form near the lake; this can be seen in the maps of tornado tracks later in this atlas. One apparent exception is in Milwaukee County. In highly urban counties there are so many people watching the skies (due to higher population density) that even small or short-duration tornadoes will be counted for the official record; they might be missed in rural counties. However, no area in Wisconsin is completely safe from the destruction of tornadoes.

METEOROLOGICAL CONDITIONS

Most days on which tornadoes form are characterized by specific weather conditions that can be used to predict the likelihood of tornadoes or severe weather. A severe storm, according to the National Weather Service, includes winds of 50 knots (58 miles per hour) or higher, hail with a diameter of 3/4 inch or more, or a tornado. The typical conditions for severe weather include

- a warm, moist layer of air at the surface, with drier air above it;
- the presence of a *jet stream* or band of high winds between 15,000 and 30,000 feet aloft;
- a marked shift in the wind direction from the surface up to the level of the jet stream, especially in the lowest 10,000 feet (a wind from the south at the surface and from the west in the jet stream is typical);
- vertical temperature variations that promote unstable conditions in the atmosphere, such as cool, dry air over warm, moist air; and
- the presence of some kind of atmospheric forcing that causes surface air to rise, such as surface heating due to strong sunlight or a nearby front, in conjunction with

dynamic forcing from the large-scale environment higher up.

When all of these conditions are present, severe weather is likely.

Generally, severe weather is most likely to develop when there is a relatively strong low pressure center with a trailing cold front to the west of your location. This places you in the southeastern quadrant of the low pressure center, commonly called the *warm sector.* Air in this region is typically much warmer and more humid than in other areas around the low pressure area. As the cold front advances toward you, thunderstorms caused by the lifting of air at the front develop and are pushed out ahead of the front by the steering of the jet stream. Some of these thunderstorms may produce heavy rain, dangerous lightning, hail, high winds, or even tornadoes.

In Wisconsin, a typical day with tornadoes usually starts with warm and humid conditions. A few fair-weather cumulus clouds may develop and grow vertically over time in the unstable air. Generally, the first sign of approaching thunderstorms is a high, thin layer of ice clouds called *cirrus* blowing off of the tops of the thunderstorms to the west. But tornadoes do not always form under these conditions. Sometimes tornadoes develop in regions where clouds cover the sky, and no indications of severe weather can be observed. Severe weather can also take place at any hour of the day or night.

National Weather Service employees use their knowledge of these severe weather predictors to issue tornado or severe thunderstorm *watches.* A *watch* is issued when conditions generally favor the development of severe weather and means that citizens should watch for changing weather conditions during the day or evening. Watches are usually issued for angled rectangular regions, called *watch boxes,* which cover a significant part of one or more states; the extent of areas within watches may be more restricted in the future due to refinements in severe storm forecasting as the National Weather Service undergoes modernization. More than 50 percent of all severe weather occurs within watch boxes. A *warning* is not issued, however, until severe weather is imminent (based on storm characteristics determined by Doppler radar) or is actually in progress (on the basis of confirmed reports by trained storm spotters).

SEVERE STORM CHARACTERISTICS AND TORNADO FORMATION

Many tornadoes form at the base of a strong thunderstorm called a *supercell.* These intense thunderstorms differ from more run-of-the-mill thunderstorms in their highly organized structure and the presence of a strong, rotating, and tilted updraft that feeds energy and moisture into the storm, maintaining it for more than an hour. Non-supercell thunderstorms usually only last for 45 minutes or less.

Rotation in a thunderstorm begins when air entering the storm near the surface is blowing from a different direction than air higher in the atmosphere. This is why observed changes of wind direction in relation to height are one important ingredient in predicting tornadoes. The rotation usually starts as a roll or horizontal rotation of the air in the lowest 10,000 feet of the atmosphere. As the updraft of the thunderstorm starts to develop, it lifts one end of the horizontal circulation and transforms it into a rotation around a vertical axis. In strong supercells, the entire thunderstorm can be observed to rotate with this vertical circulation. Most supercells rotate cyclonically (counterclockwise in the Northern Hemisphere), but either direction is possible, and some strong anticyclonic tornadoes have been seen.

The precise development of a tornado from this vertical rotation is the subject of intense study by meteorologists and is not known in detail at this time. However, scientists believe the tornado develops as a more concentrated vortex near the boundary between the strong updraft and a downdraft of cool air on the rear edge of the supercell. The intense circulation of the tornado usually begins in the middle levels of the thunderstorm, stretching up and down until it eventually reaches the ground. Sometimes the visible funnel *(condensation funnel)* of the tornado can be seen reaching down from the clouds like a giant finger, but the visible part of the tornado can also develop from the ground up, particularly in drier conditions. Thus, a damaging storm can be present even when no funnel is seen touching the ground. Trained storm spotters are taught to look for clouds of debris circulating on the ground; these clouds can indicate the presence of a tornado even without a visible funnel.

Once a tornado forms, it goes through a typical life cycle that has been well documented by tornado spotters. The first stage of the tornado is usually the dust whirl stage, in which the tornadic circulation is fully developed from the cloud to the ground, but a complete funnel cloud touching the ground may not yet be visible. The funnel cloud reaching down from the supercell may appear to come from a lowered section on the base of the cloud known as the *wall cloud*. Most tornadoes form in or near a rotating wall cloud. As the tornado develops, the funnel becomes fully visible and increases in size and strength until it reaches its maximum size and intensity and is considered mature. In this stage, one or more vortices may be present, rotating around the center of tornadic circulation.

A spectacular mature multiple vortex tornado was photographed crossing the west side of Oshkosh on April 21, 1974. This tornado caused $5 million in damage and injured 35 people, but no one was killed. Figure 1 shows a sequence of four photographs from this storm. They were taken just a few seconds apart from south of Oshkosh by Rusty Kapela of the National Weather Service and show the changing nature of the tornado funnels.

After a tornado matures, it begins to shrink and tilt as the energy to the storm begins to cut off. Generally, the funnel at the surface lags behind the tornado in the air. This may be due to frictional effects or to the influence of downdrafts blowing the circulation sideways. Unlike the sweeping motion a fictional tornado has in movies such as "The Wizard of Oz," however, tornadoes tend to move in straight lines, not from side to side. As a tornado shrinks in diameter, the winds can spin up to even higher speeds and can become extremely dangerous, even when the tornado was weak prior to shrinking. At that time, a new tornado may be forming farther to the south in the same supercell or the thunderstorm may be dissipating. As the tornado continues to contract, the funnel can be stretched into a rope-like form that still may have a small but intense circulation near the ground and eventually dissipates. In Wisconsin, this visual life cycle is usually obscured by rain.

Tornadoes that form in the Tornado Alley region of the Great Plains commonly fit this description of classical tornado development, but tornadoes in Wisconsin can also form in this manner. However, tornadoes do not always develop in supercell storms, and non-classically formed small tornadoes can also do significant damage to buildings or people. Small tornadoes can form in other regions where the wind changes direction rapidly, such as *gust fronts*. A gust front is the boundary between the ambient air surrounding a thunderstorm and the cooler, moister air flowing down and out from within the thunderstorm. Typically, the winds at this boundary are fast and variable, leading to an increase in gusts. Gust front tornadoes are known as *gustnadoes* by tornado researchers and are usually weak, but may still be strong enough to do significant damage, particularly to mobile homes and garages. Some scientists do not consider them tornadoes at all.

Other weak tornadoes can form when shallow cumulus clouds form in regions of cold, unstable air *(cold air funnels)*. A cold air funnel tornado did significant damage to a car dealership on the northeast side of Madison on June 14, 1989. A third type of relatively weak tornado is called a *landspout;* it forms along zones in which winds blowing from different directions clash and the rotation caused by this encounter is enhanced by growing clouds aloft. The July 5,

Rusty Kapela

Figure 1. Four views of the Oshkosh tornado of April 21, 1974, looking north.

1994, Cooperstown (Manitowoc County) landspout tornado formed when rotating air along the border between a cold front and the lake breeze blowing inland from Lake Michigan was stretched into a full-scale vortex when a thunderstorm passed overhead. This tornado caused $2.1 million in damage to 26 houses, 19 vehicles, a mobile home, and three barns, but only two people were injured.

OTHER TYPES OF RELATED SEVERE WEATHER

Tornadoes are not the only type of extreme weather that can cause significant damage to property, animals, and humans. Several other kinds of weather events can produce just as much damage as weak or even moderate tornadoes if they hit a vulnerable spot. These phenomena can be loosely lumped into the categories of other types of vortices, other extreme winds, and other thunderstorm dangers.

Other types of vortices. A tornado is the most powerful type of local atmospheric vortex known to humans. But there is actually a wide range of rotating winds that can be seen in the atmosphere, ranging from the 1,000-mile-wide midlatitude low pressure area to the hurricane to the tornado and down to the lowly whirls of leaves that swirl at the Earth's surface in the fall. Some of these vortices can also cause damage or injury, although they are usually confined to a smaller area and are less severe. These eddies include *waterspouts*, *dust devils*, and *fire devils*.

Waterspouts come in two classes: Some are merely tornadoes that have moved over water and contain all the characteristics of tornadoes described above; the rest are smaller and tamer whirls that develop in a very different way. Unlike tornadoes, the second class of waterspouts usually forms from growing cumulus clouds rather than thunderstorms and has wind speeds that seldom exceed 140 miles per hour. They are usually seen over the ocean surrounding Florida, although they have also been observed over the Great Lakes in summer and early fall. If they move over land, they can produce damage at the shoreline, but they usually dissipate quickly after moving away from water.

Dust devils are even smaller and less dangerous than non-tornadic waterspouts, but can cause damage to small sheds directly in their path. Dust devils form over hot surfaces, under clear skies and light winds. Their circulation and vertical structure is delineated by dust picked up from the ground. Occasionally, another lightweight substance such as hay exposes the spinning motion instead. Dust devils rarely reach up to cloud level, and are seldom more than 1,000 feet high. In Wisconsin, they are quite rare. On May 6, 1995, a dust devil near Minong in Washburn County damaged the roof of a house, tore through a snow fence, and caused a small fire when it downed power lines. A path of destruction marked the whirlwind's trail for 300 yards. Most dust devils in Wisconsin are much smaller than those in the western United States, where they are usually observed over the hot surfaces of the desert Southwest, although they can also form over concrete or asphalt parking lots or open fields.

Fire devils are vortices formed in the heat of air rising from large fires. Many fire devils have been seen over forest fires in the western United States; they are outlined by the smoke that pours off the fires. Eyewitnesses to the fire at Williamsonville, Wisconsin, on October 8, 1871 (the same day as the famous Peshtigo fire), reported seeing "tornadoes of fire" that accompanied the wildfire. Moran and Somerville (1990) showed a 1878 map of Door County in which the town "Tornado" marked the place where the devastated Williamsonville was previously located. Fire devils also occurred during the 1920s in the great Tokyo earthquake and fire. Fire devils only form where a fire is active.

Other types of extreme winds. Winds do not need to rotate in order to do extreme damage. Some of the most devastating severe weather events in Wisconsin history have been caused by straight-line winds. These bursts of racing winds can be confined to small, localized patches or may spread in long lines that march the width of the state.

Small-scale wind damage is usually caused by phenomena called *downbursts* or *microbursts*. In a downburst, strong localized winds form in the downdraft of a thunderstorm and plummet toward the ground. When the burst of air hits the ground, it spreads out horizontally, damaging trees and buildings with its strong winds. Typically, the winds are 50 to 80 miles per hour, although they can reach as much as 150 miles per hour. Although the winds do not rotate, they can cause debris to appear twisted because of uneven structural failure or interaction between falling trees. Because of this, damage from downbursts has sometimes been classified as tornado damage even though no funnels were seen. They have also been incorrectly called "upside-down tornadoes" by overzealous reporters.

Downbursts can last from 5 to 60 minutes and can sometimes form in groups or clusters. One of the most damaging downburst clusters in Wisconsin history developed in northern Wisconsin on July 4, 1977. On this day at least three separate clusters with 25 downbursts caused about $20 million in damage over a three-hour period. The damage covered a swath 166 miles long and up to 17 miles wide, including 840,000 acres of timber flattened by winds of more than 100 miles per hour. The airport at Rhinelander had a measured gust of 120 miles per hour. One child was killed in a camper during the storm and 35 people were injured. Grazulis (1993) reproduced a figure by Dr. T.T. Fujita showing the detailed multi-burst structure of the storm cluster.

On rare occasions, the thunderstorm complex that produces these downburst clusters can become highly organized, gaining the ability to last for many hours and cross several states. This type of severe weather system is called a *derecho*, based on a Spanish word that means straight ahead or direct. These systems were first recognized in 1888 in a paper by Hinrichs, but the name was not commonly used by meteorologists until 100 years later. Derechos are most common from May through August and generally follow a northwest–southeast track at speeds ranging from 35 to 70 miles per hour.

One of the most dramatic examples of a derecho in Wisconsin was the July 7, 1991, derecho that affected southern Wisconsin in the late afternoon. This event was actually the second of two derechos that developed in the Midwest on that Sunday; the trail of the two storms stretched in a line from eastern South Dakota to central Pennsylvania. The derecho that affected Wisconsin developed around 1 pm CDT in eastern Iowa and moved rapidly toward the east. Madison experienced its peak wind gust of 83 miles per hour at 3:02 pm CDT. By 4 pm the storm was affecting the western suburbs of Milwaukee; by 5 pm, the derecho had crossed most of Lake Michigan. Total damage from the storm was estimated to be more than $20 million. Fortunately, only four people were injured in Wisconsin in the storm and no fatalities were reported. A few small tornadoes were spotted with the storm, but caused little damage compared with the damage from the straight-line winds. Another strong derecho event passed through in central and southern Wisconsin on July 19, 1983.

Because non-tornadic storms can produce as much damage as tornadoes, citizens should also pay just as much attention to severe thunderstorm watches and warnings as to tornado watches and warnings. Tornadoes sometimes develop in regions where they are not expected, but where other types of severe weather were forecast. The devastating Plainfield, Illinois, tornado of August 28, 1990, formed during a severe thunderstorm warning rather than a tornado warning. Twenty-nine people were killed and 350 injured in this storm. Even if no tornado is spotted, tornado safety rules should be followed because straight-line winds in severe storms can be as dangerous as tornadoes.

Other thunderstorm dangers. Even when there are no tornadoes or damaging high winds, thunderstorms can cause damage or harm to property, people, and animals. Every thunderstorm produces lightning, which can injure or kill people working or playing outside or even, on rare occasions, people inside houses. Lightning also causes damage to trees and property by shorting out power lines and igniting fires. Some thunderstorms also produce intense bursts of rainfall, which can cause flash flooding, especially in areas that have significant topographic relief or in urban areas where many surfaces are paved over. Some severe thunderstorms can also produce hail, which causes major property damage to crops and buildings, especially when the hail is large and is combined with high winds that blow the hailstones sideways into windows and siding. Animals and people caught outdoors without shelter have been killed by the force of large falling hailstones.

DATA SOURCES

To do a good scientific analysis of storm climatology, scientists need to have a consistently acceptable level of historical data. This means that the data set must have good areal and temporal coverage of tornadoes. The paragraphs below describe the sources of tornado data available for this study.

HISTORICAL RECORDS PRIOR TO 1950

The earliest records of tornadoes in Wisconsin were collected by Lieutenant Finley of the U.S. Signal Service and published in a paper in 1888. His map of tornado tracks in Wisconsin (fig. 2) shows the paths of all known tornadoes that were witnessed in the state from 1844 to 1880. The paths of the tornadoes are shown as lines or circles leading from west to east. However, observations of tornadoes in the early years were subjective and based on imperfect evidence from observers, who were sometimes known to exaggerate the strength and nature of the storms. This is particularly true of the storms with the longest tracks, such as the improbable storm track stretching from Grant County all the way to Winnebago County. This may have been the track of a family of tornadoes formed from a single long-lasting supercell, or may have been the combination track of several unrelated tornadoes that happened to form on the same day. Some of the "tornadoes" on this map may in fact have been downbursts or derechos rather than real tornadoes. Because the quality of these early records is poorly documented, they are not generally used in tornado climatologies.

After 1888, tornado information was collected in a haphazard way by the U.S. Weather Bureau. Reports tended to come preferentially from the better-settled parts of Wisconsin, where more people could see a storm, or from areas with forests that could show clear evidence of a storm after it passed. Local papers also often published accounts of storms that affected their regions, but these accounts may not have been investigated by Weather Bureau personnel. As the state became more highly settled and the network of regular weather observers expanded, reports became more uniformly distributed in space; fewer tornadoes were probably missed in tornado statistics. However, because of the uncertainties in locating and describing the paths and strengths of tornadoes before 1950, these tornadoes are also not included in the climatological statistics presented in this atlas—except for the map of killer tornado paths, which includes all known killer tornadoes and their best available path information. Information about characteristics of earlier storms is available in Burley and Waite (1965), Clark and Norgord (1986), Norgord (1992), and Grazulis (1993).

One of the best documented early tornadoes in Wisconsin was the devastating New Richmond tornado of 1899. The tornado developed late in the afternoon of a day when a traveling circus was visiting and had drawn more than 1,000 extra people to town. The storm was extensively documented by Mrs. Anna Epley, the wife of one of the town's doctors, who interviewed many members of the community following the terrible disaster. Her riveting account was reprinted in Epley (1988). This tornado was observed to form over the St. Croix River south of Hudson, and moved to the northeast, destroying farm buildings along its path. When it reached New Richmond, the circus had just let out, and 117 people were killed and 125 injured by the violent storm. The town was completely ruined. To this day, the New Richmond

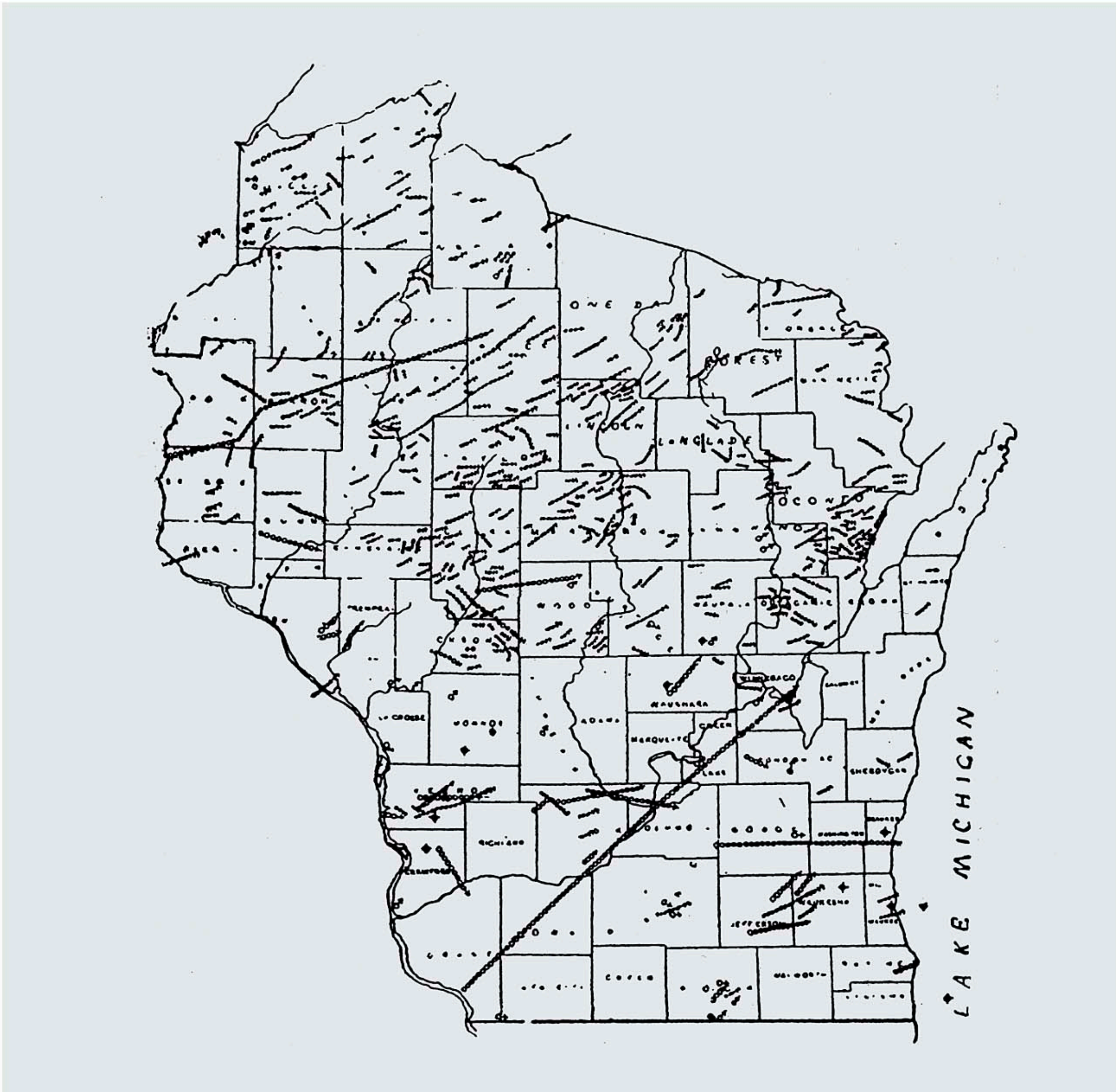

Figure 2. Tornado paths of Wisconsin tornadoes, 1844–80, from Finley (1888).

tornado remains the deadliest storm in Wisconsin history.

STATISTICAL RECORDS FROM 1950 TO THE PRESENT

Since 1950, tornado records have been kept in a systematic way by the National Weather Service and their descriptions have been published in *Storm Data*. Additional information on path location may be available from local media or National Weather Service records, although they are not always published. The National Weather Service records are stored in the TD-9714 archive at the National Climatic Data Center, which lists location, time, path characteristics, and damage and injuries associated with each event. It also lists an intensity–damage rating called the Fujita Scale, which characterizes the approximate strength of each event on a scale from 0 to 5. (This scale is described in more detail in the *Distribution of* *tornadoes over space—Numerical and spatial distribution of tornadoes, by county* section.) Tornadoes from the period before the development of the intensity scale in 1971 were given an estimated intensity based on known damage and storm characteristics.

Although the reports compiled after 1950 were gathered in a more complete and systematic way than earlier ones, there may still be an undercount in the total number of tornadoes in the early years. As public awareness of tornadoes and severe weather has increased, reporting and investigating storms has become more common, and numbers of tornadoes observed across the country each year continue to grow. Figure 3 shows the yearly variation of numbers of Wisconsin tornadoes and tornado days (number of days on which one or more tornadoes were observed in Wisconsin) from 1950 to 1996; the increase in the number of reports over time can easily be seen in the first decade.

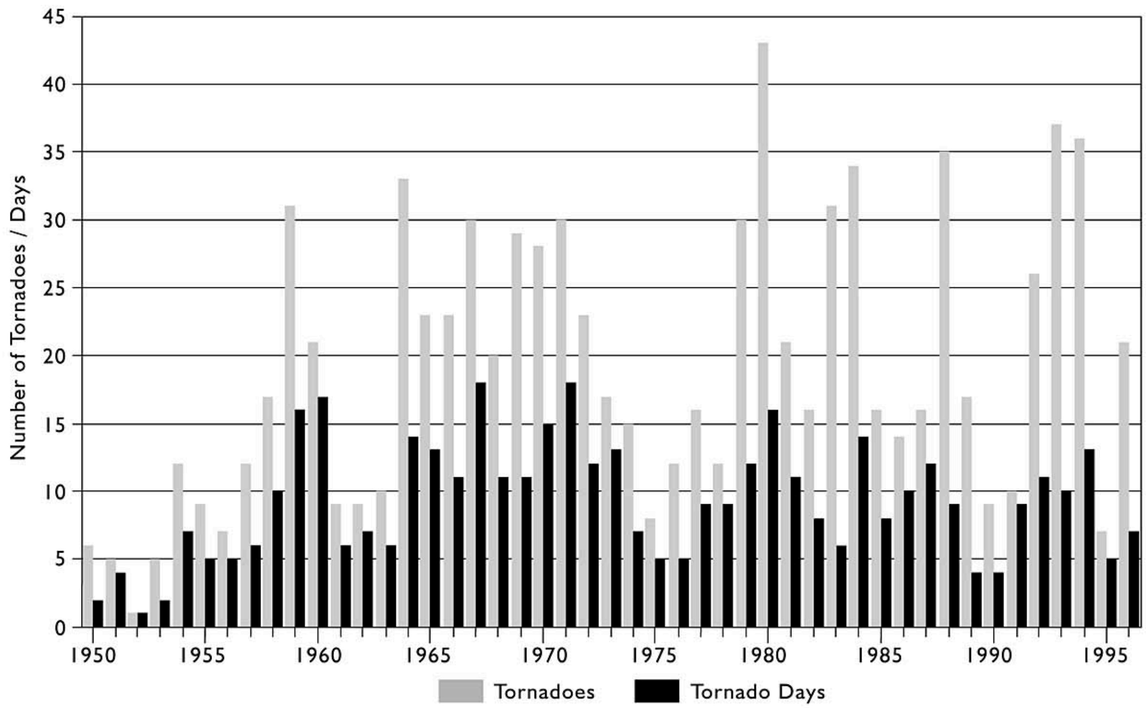

Figure 3. Number of tornadoes and tornado days per year.

CHARACTERISTICS OF TORNADO CLIMATOLOGY

BASIC INFORMATION

During the 47-year period from 1950 to 1996, 891 tornadoes were documented across Wisconsin, giving an annual average of approximately 19 tornadoes. Tornadoes have formed in every month except February. These storms took place on 433 separate days (giving an average of 2.1 tornadoes per tornado day) and caused 1,547 injuries and 95 deaths. The largest single number of deaths was recorded in 1958, when 20 people were killed by a single tornado that traveled east–northeast from St. Croix to Dunn County on June 4. Eight people were killed by two other tornadoes on the same day in Chippewa, Clark, and Marathon

Counties. On average, two people are killed and 33 injured by tornadoes each year.

DISTRIBUTION OF TORNADOES OVER TIME

Daily distribution of tornadoes, by time. Figure 4 shows the distribution of tornadoes over the day. The late afternoon peak of the distribution is due to the influence of strong solar heating of the Earth's surface on the triggering of severe thunderstorms, which can quickly form tornadoes. Although tornadoes are most likely to form in the period between mid-afternoon and early evening, they have been observed at every time of day. This is because surface heating is not the only mechanism for forming severe storms. The devastating Barneveld tornado of 1984 began just before midnight on June 7 as a cold front approached from the west. Most of the nine deaths and 200 injuries from the storm were sustained when the tornado ripped apart homes as people slept.

Annual distribution of tornadoes, by month. Tornadoes have developed in Wisconsin in every month except February during the period 1950–96. However, as figure 5 shows, the majority of tornadoes form in the late spring and early summer, with a sharp cutoff after September. The earliest spring tornadoes are usually observed in southern Wisconsin, with the crest of activity moving northward as spring heating progresses through the state. This can be seen in more detail in the month-by-month track maps in the *Distribution of tornadoes over space—Spatial distribution of tornadoes, by month* section. Climatologically, this early summer peak is to be expected because this is the time of year during which temperature variations across the region are most pronounced and the atmospheric dynamics that promote the growth of severe storms are strongest. The continuing activity in September reflects the presence of high temperature contrasts and strong atmospheric dynamics in the region as the main axis of atmospheric activity shifts south.

DISTRIBUTION OF TORNADOES OVER SPACE

Spatial variability of tornadoes, by decade. Because tornadoes are rare and more or less random, small-scale phenomena, tornado occurrence from one decade to the next can be dramatically different. In figures 6–10, decade-by-decade path maps for Wisconsin tornadoes illustrate this point. The paths of all tornadoes within a decade are drawn on each map as lines showing the path of each tornado on the ground. Tornadoes shown by dots indicate very short or unknown paths. Unless otherwise indicated

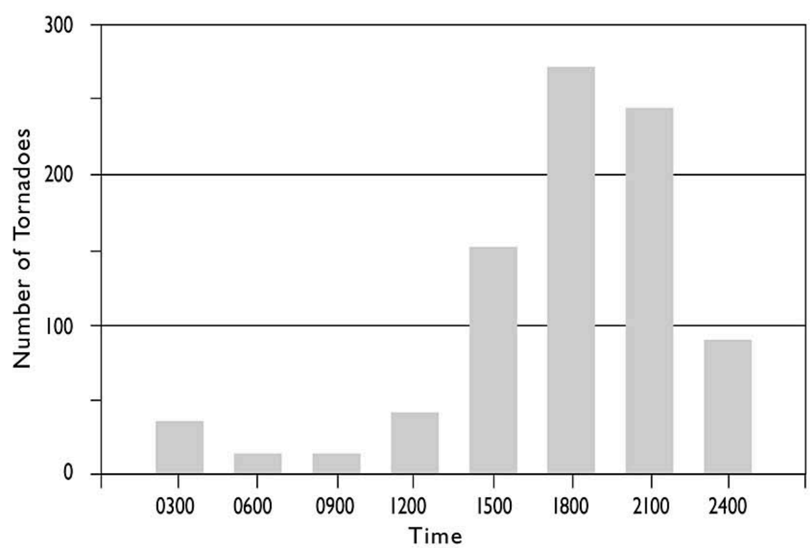

Figure 4. Number of tornadoes by time of day for each three-hour period.

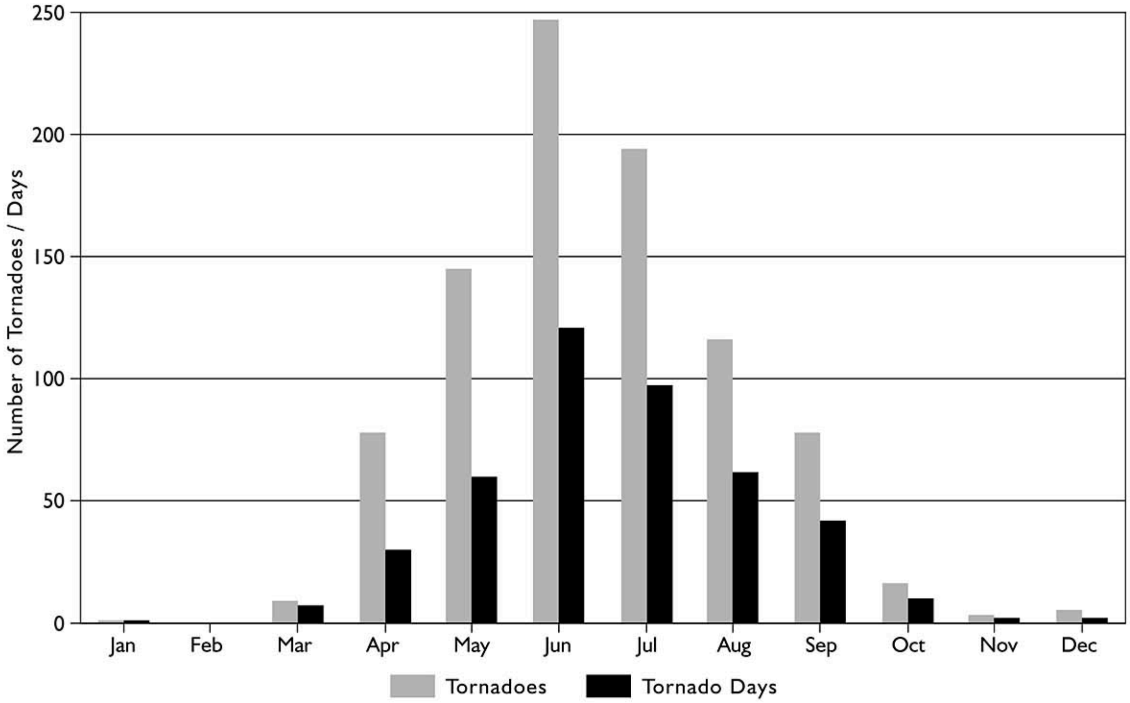

Figure 5. Number of tornadoes and tornado days per month.

on the map, all tornadoes moved from the western ends of their paths toward the eastern ends.

A comparison of path maps from one decade to the next shows significant variations in the number and location of tornadoes spotted. For example, there were almost twice as many tornadoes during the 1960s as in the previous decade. This may partially reflect the accuracy of the count and not a real difference in tornado frequency. Spatial patterns also change notably from one decade to the next. Note the great concentration of tornadoes near Dodge County in the 1970s compared with the previous two decades and the large number of tornadoes in southwestern Wisconsin in the 1980s compared with the 1970s. However, these maps can be somewhat misleading because most of the southwestern tornado tracks in the 1980s resulted from a single outbreak on June 7–8, 1984 (including the Barneveld tornado).

One especially dramatic pattern is the high concentration of tornadoes in central Wisconsin in the first seven years of the 1990s compared with the other decadal maps. Sometimes the memories of residents in these situations can lead to their perception of local "tornado alleys," although a look at the longer record usually eliminates those ideas. There is no good climatological explanation for the change of these patterns over time, although they may be linked to continental variations in weather patterns on the same time scales.

Spatial distribution of tornadoes, by month. As you have seen in the previous section, the display of tornado tracks by location can provide significant information about tornado density and climatological likelihood of occurrence at a given site as well as information about preferred path direction and length. In this section, tornado tracks are separated by month to illustrate the distribution of tornadoes over time and space.

Figures 11–22 show the tornado paths distributed by month of the year during 1950–96. The maps show that very few tornadoes are observed before April and after September, as is expected from climatological arguments. In April, the number of tornadoes increases dramatically, especially in the southeastern half of Wisconsin, because warm humid air invades the state more frequently

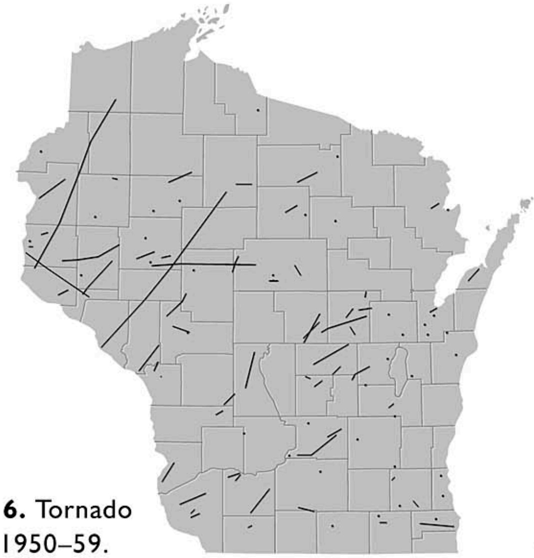

Figure 6. Tornado tracks, 1950–59.

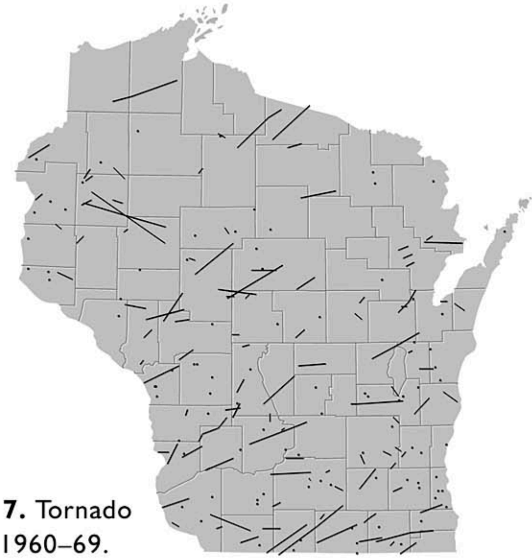

Figure 7. Tornado tracks, 1960–69.

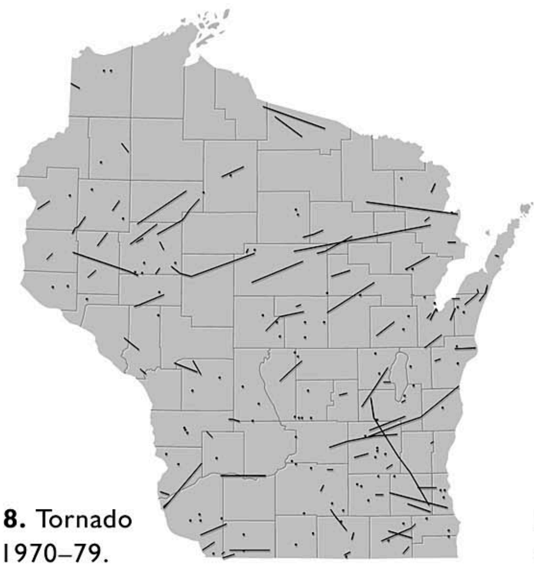

Figure 8. Tornado tracks, 1970–79.

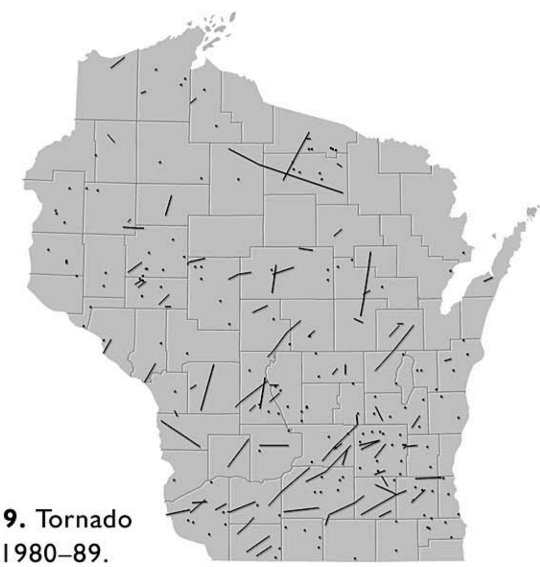

Figure 9. Tornado tracks, 1980–89.

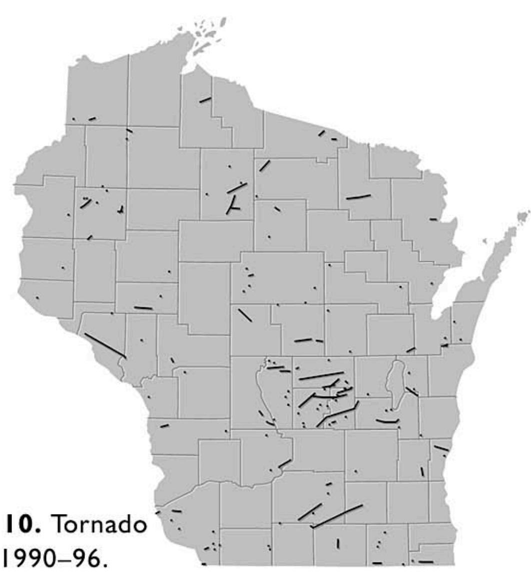

Figure 10. Tornado tracks, 1990–96.

in conjunction with active cold fronts. These conditions are perfect for tornado formation, as described previously in the section *Typical conditions associated with Wisconsin tornadoes*. Note that many of the April tracks are oriented more north–south than tracks later in the year. Strong southerly winds high in the atmosphere steer the severe storms from which tornadoes develop in this month.

In May tornadoes have been observed in many parts of the state, with the exception of the far northern counties. These counties reach their peak tornado occurrence in June and July, when temperature and humidity reach their highest levels. May and June are

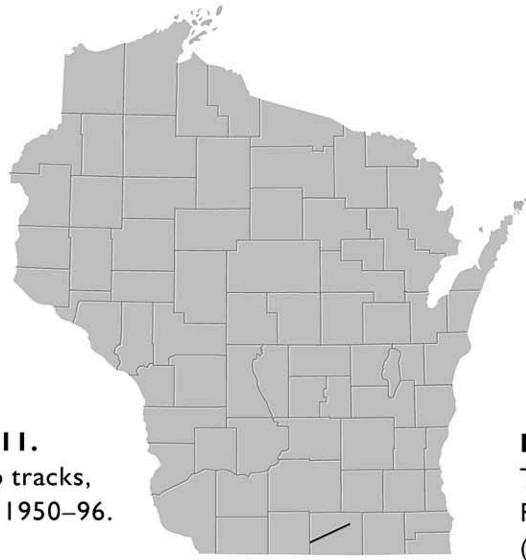

Figure 11.
Tornado tracks,
January, 1950–96.

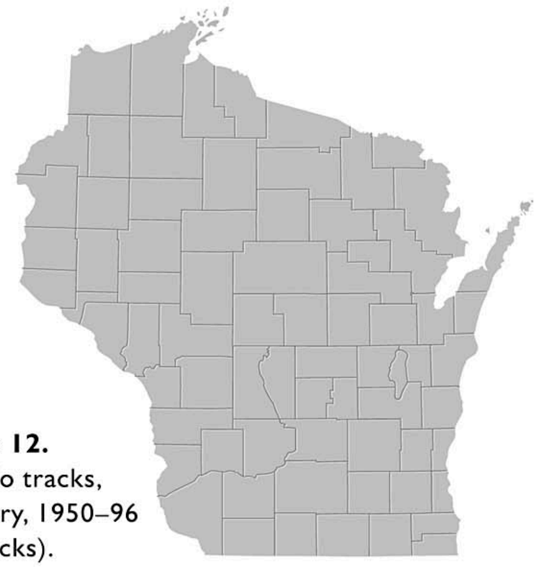

Figure 12.
Tornado tracks,
February, 1950–96
(no tracks).

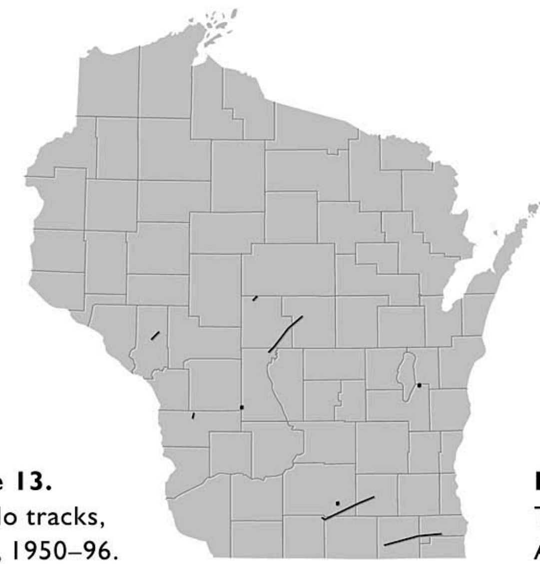

Figure 13.
Tornado tracks,
March, 1950–96.

Figure 14.
Tornado tracks,
April, 1950–96.

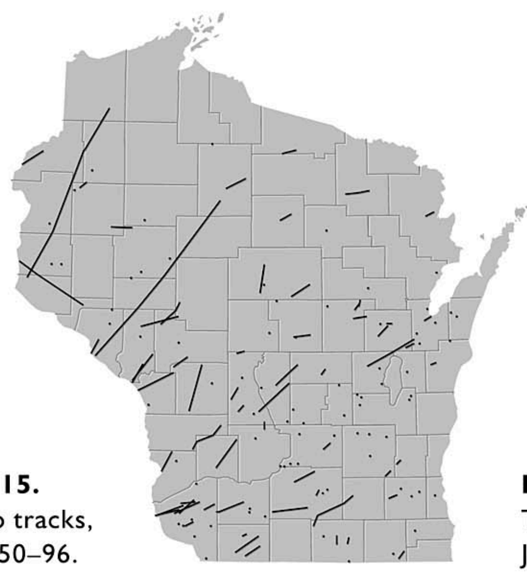

Figure 15.
Tornado tracks,
May, 1950–96.

Figure 16.
Tornado tracks,
June, 1950–96.

Figure 17.
Tornado tracks, July, 1950–96.

Figure 18.
Tornado tracks, August, 1950–96.

Figure 19.
Tornado tracks, September, 1950–96.

Figure 20.
Tornado tracks, October, 1950–96.

Figure 21.
Tornado tracks, November, 1950–96.

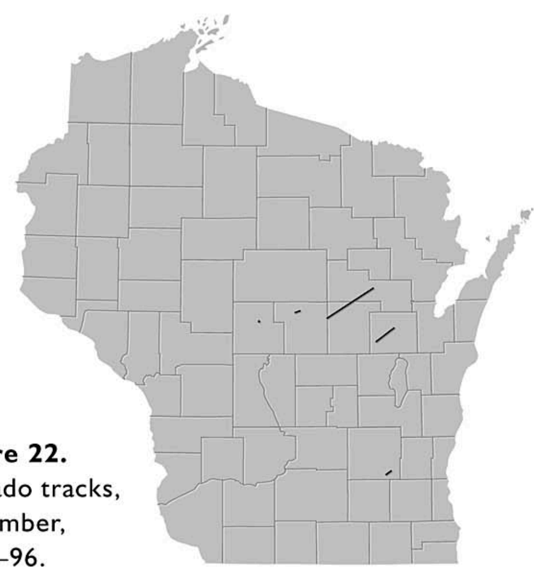

Figure 22.
Tornado tracks, December, 1950–96.

the peak months for tornadoes in Wisconsin overall. By July the number of tornadoes in the state begins to decrease. The short paths of many of the tornadoes indicate that they are mainly weak storms of short duration that may cause little damage unless they hit a vulnerable location. Also note that some of the storms have a northwest–southeast path, in contrast to most other months. Many of these storms may be associated with other types of severe weather such as downburst clusters (derechos), which tend to move in this direction.

In August and September, tornado path lengths tend to increase again as the severe storms become more vigorous. Path directions also tend to be more west–east in orientation, reflecting the steering wind patterns at higher altitudes. After September, tornadoes become uncommon, developing mainly when warm, humid air makes a rare incursion into the state from the south.

Figure 23 shows the combined tornado path map for all months. Dots represent brief tornado touchdowns that had no appreciable path lengths. The map shows that over the 47-year period tornadoes were fairly evenly distributed across the state, except for the far north and near the shore of Lake Michigan where, climatologically, se-

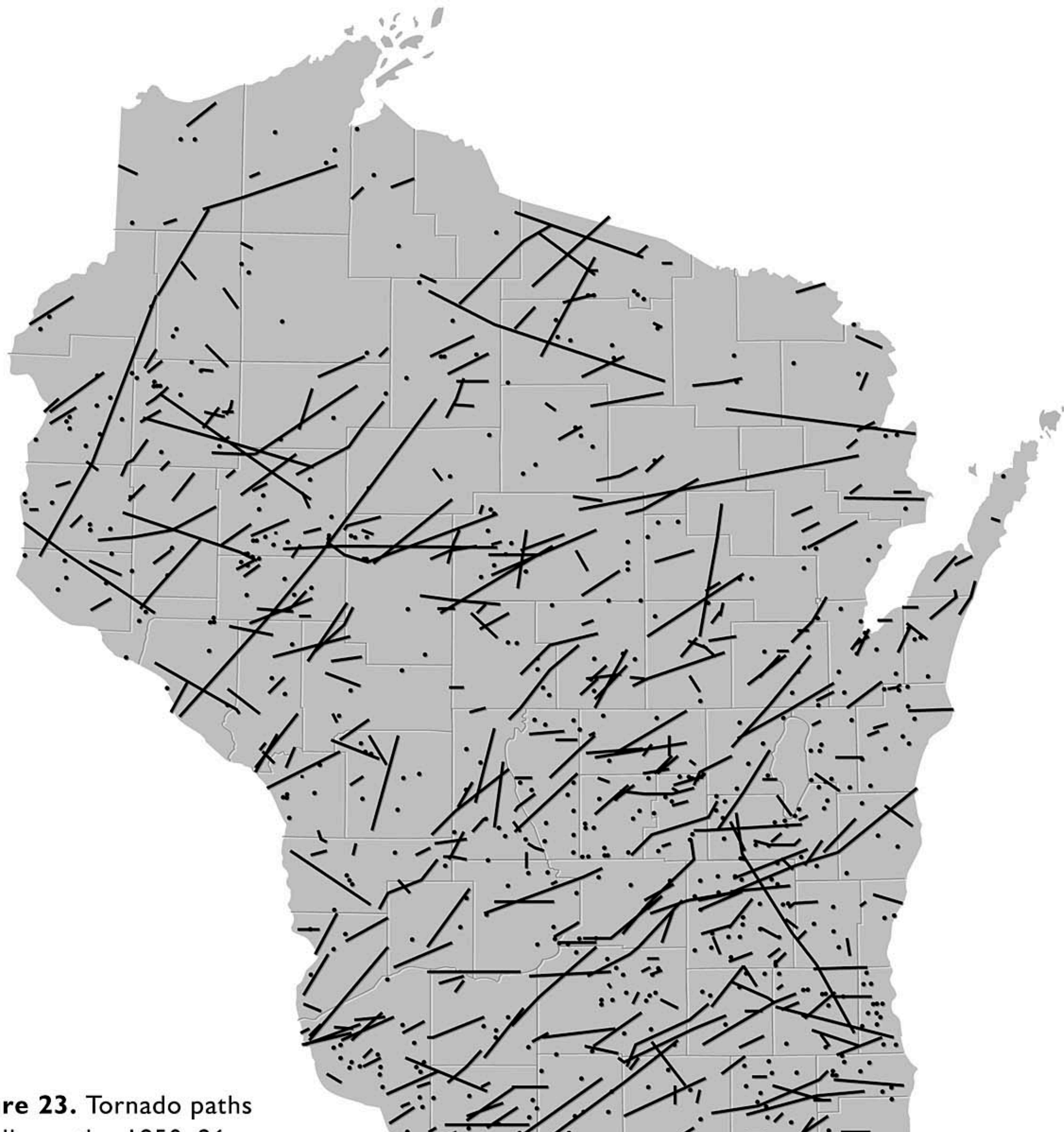

Figure 23. Tornado paths for all months, 1950–96.

vere storms are less common. The spatial variations from one decade to the next can also be seen to be random fluctuations over time when compared with the complete picture. (The relatively low-density patch centered on eastern Jackson County is probably due to the irregular nature of tornado formation over time rather than a true climatological anomaly and would disappear if tracks from 1880 to 1949 were included; see Grazulis (1993, p. 452–453.) If you look at the state as a whole, there is little evidence to support the idea of localized tornado alleys, although this short record does show some places that have been hit more often in the past 47 years than others.

Numerical and spatial distribution of tornadoes, by county. Table 1 shows the number of tornadoes experienced by county during the 1950–96 period. The total number of tornadoes listed is larger than the total number of tornadoes observed in the state because some tornadoes crossed county lines and thus were counted in two counties. This information is also shown in figure 24, on which the touchdown points of the tornadoes are shown as dots. Some of the larger counties, such as Grant, Marathon, and Dane, have higher number of tornadoes because they encompass more land area than smaller counties, such as Pepin or Kenosha. Population density can also affect the number of tornadoes observed because the greater the number of people, the more likely a tornado is to be spotted; for example, this probably explains the slightly larger number of tornadoes observed in Brown County compared with its neighboring counties.

DISTRIBUTION OF TORNADOES, BY INTENSITY

Measurements of tornado intensity and damage are highly subjective estimates because of the variable strengths of buildings and trees that are downed by direct contact with tornado funnels. However, following the Lubbock, Texas, tornado of May 11, 1970, Dr. Theodore Fujita of the University of Chicago devised a seven-level scale as an attempt to relate wind speed ranges to various degrees of structural damage. This Fujita Scale (also called the F-scale) has become the standard scale used to describe tornadoes by their intensity. The levels of the F-scale are shown in table 2. Estimates of the F-scale for each tornado are usually made after the tornadic debris can be examined and the extent of the damage resolved. Tornadoes may be rated at different F-scales at different points in their paths and histories, as the storm strengths and building materials they hit change.

Figures 25–30 show the distribution of

Table 1. Distribution of tornadoes by county, 1950–96.

Adams	20	Douglas	8	Kewaunee	9	Ozaukee	14	Taylor	7
Ashland	6	Dunn	10	La Crosse	11	Pepin	5	Trempealeau	15
Barron	27	Eau Claire	18	Lafayette	20	Pierce	13	Vernon	16
Bayfield	5	Florence	1	Langlade	5	Polk	14	Vilas	14
Brown	18	Fond du Lac	34	Lincoln	10	Portage	18	Walworth	21
Buffalo	11	Forest	4	Manitowoc	15	Price	15	Washburn	6
Burnett	7	Grant	41	Marathon	28	Racine	14	Washington	9
Calumet	14	Green	15	Marinette	16	Richland	7	Waukesha	23
Chippewa	32	Green Lake	21	Marquette	19	Rock	18	Waupaca	13
Clark	19	Iowa	13	Menominee	2	Rusk	8	Waushara	15
Columbia	21	Iron	3	Milwaukee	18	St. Croix	19	Winnebago	11
Crawford	9	Jackson	12	Monroe	13	Sauk	16	Wood	12
Dane	37	Jefferson	16	Oconto	10	Sawyer	7		
Dodge	45	Juneau	23	Oneida	15	Shawano	12		
Door	6	Kenosha	4	Outagamie	14	Sheboygan	7		

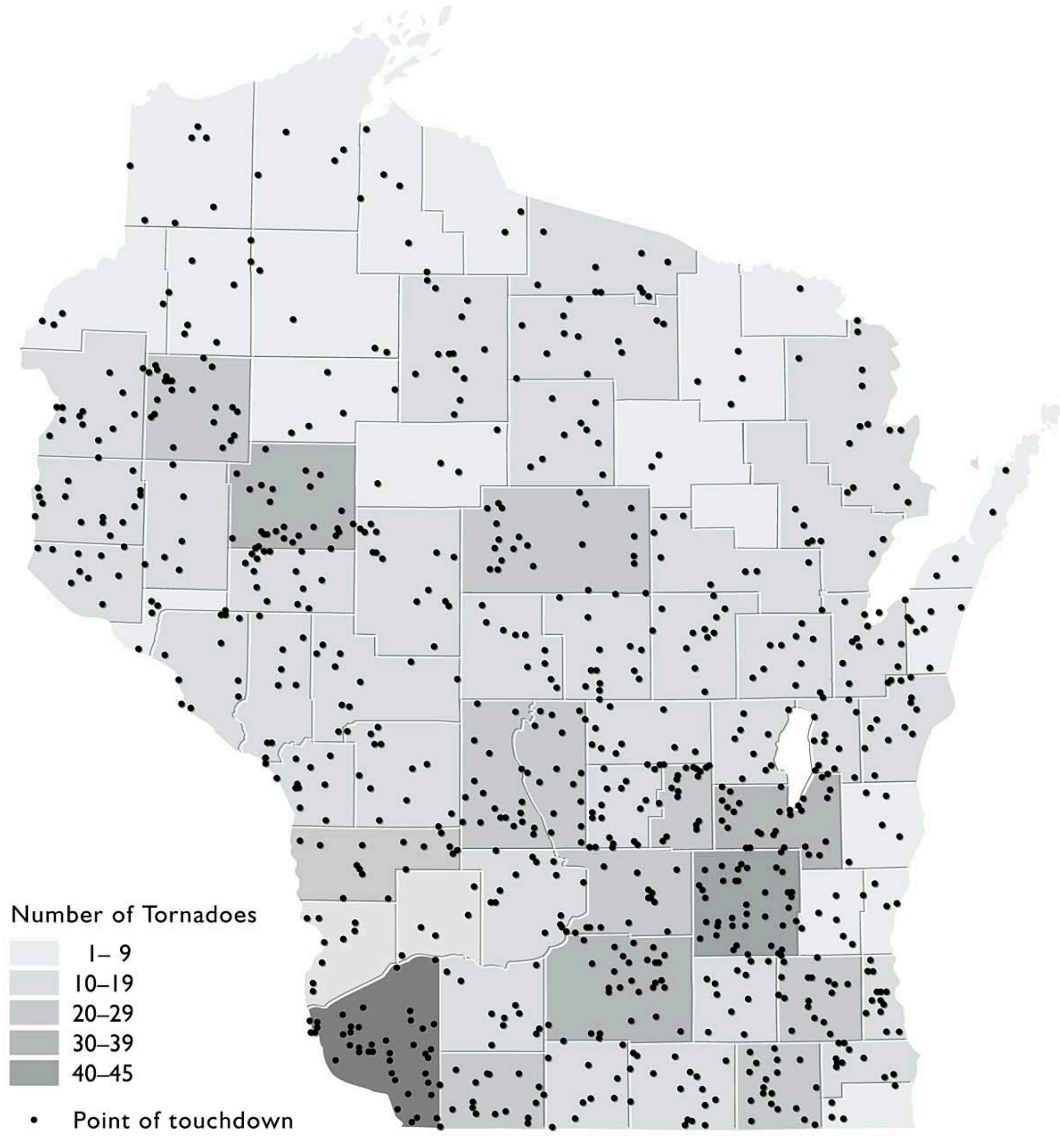

Figure 24. Number of tornadoes per county, 1950–96.

tornado tracks by F-scale rating for 1950–96. Tornadoes are classified by the highest F-scale they reach. The figures show that the low intensity tornadoes tend to have shorter path lengths and durations than high intensity tornadoes. They also show that, in general, the higher the intensity, the fewer tornadoes there are, with the exception that the number of F1 tornadoes is larger than F0 tornadoes. This irregularity may be partially explained by the fact that many of the smallest tornadoes are not observed because they last such a short time and are only reported if they actually hit something and cause significant damage. Also, damage from F0 tornadoes is many times reported as unspecified wind damage rather than as a tornado touchdown.

Table 2. Fujita Scale standards (adapted from *Storm Data*, U.S. National Oceanic and Atmospheric Administration).

Fujita Scale	Wind-speed range	Description
F0	40–72 mph Gale tornado Light damage	Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; signboards damaged.
F1	73–112 mph Moderate tornado Moderate damage	Lower limit (73 mph) is the beginning of hurricane wind speed; surfaces peeled off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off roads.
F2	113–157 mph Significant tornado Considerable damage	Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light-object missiles generated.
F3	158–206 mph Severe tornado Severe damage	Roofs and some walls torn off well constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off ground and thrown.
F4	207–260 mph Devastating tornado Devastating damage	Well constructed houses leveled; structures with weak foundation blown off some distance; cars thrown and large missiles generated.
F5	261–318 mph Incredible tornado Incredible damage	Strong frame houses lifted off foundations and carried considerable distances to disintegration; automobile-sized missiles fly through the air in excess of 100 meters; trees debarked; incredible phenomena occur.
F6	319–379 mph Inconceivable tornado	Maximum speeds of tornadoes are not expected to reach the F6 wind speeds.

Tornadoes rated as F2 and F3 are relatively evenly distributed across the state; F4 and F5 tornadoes are so rare that it is difficult to make any conclusions about their relative likelihood in any one area. In fact, the only F5 tornadoes that occurred in 1950–96 were the Barneveld tornado of June 7–8, 1984, and the Oakfield tornado of July 18, 1996. However, we know from historical photographs of tornado damage that there have probably been at least three other F5 tornadoes in Wisconsin history, including the May 22, 1893, tornado north of Darlington in Lafayette County, the May 18, 1898, tornado in northern Marathon County, and the New Richmond tornado (St. Croix County) of June 12, 1899. It is not surprising that most of the strongest tornadoes have formed in late May and early June because this is when the meteorological factors for tornado development are most favorable. However, the Oakfield tornado proved that they can develop at other times, too.

DISTRIBUTION OF TORNADO INJURIES AND DEATHS

Although tornadoes can be magnificent when viewed from a safe distance, the consequences of tornadoes can be tragic when lives or property are lost. No climatology of Wisconsin tornadoes would be complete without mentioning the people most affected by these violent storms—those injured and killed. Fortunately, with the modernization and educational efforts of the National Weather Service and the hard work of emergency government agencies and storm-spotter associations, the number of people hurt by these storms has declined dramatically since the 1960s, and it is no longer uncommon to have a year in which no one in Wisconsin is killed by severe weather. As technology and warning capability improve, this trend should continue.

Deaths from tornadoes have been reported in every month from March to

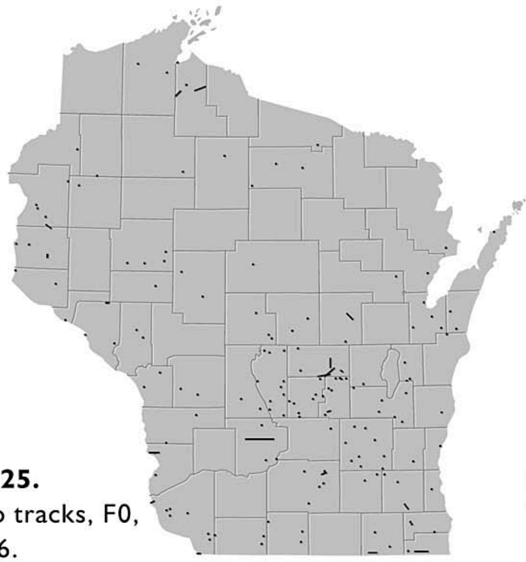

Figure 25.
Tornado tracks, F0, 1950–96.

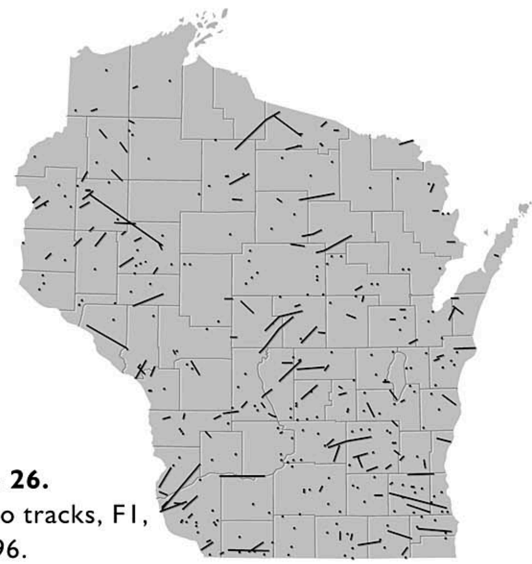

Figure 26.
Tornado tracks, F1, 1950–96.

Figure 27.
Tornado tracks, F2, 1950–96.

Figure 28.
Tornado tracks, F3, 1950–96.

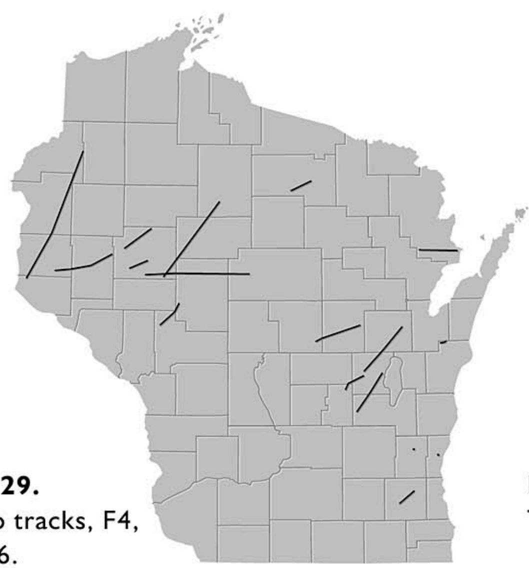

Figure 29.
Tornado tracks, F4, 1950–96.

Figure 30.
Tornado tracks, F5, 1950–96.

November, but the majority of "killer" tornadoes affects Wisconsin in June, when the tornado season reaches its peak. June also has by far the most deaths of any month; many of these are attributable to a few storms in years such as 1899, 1958, or 1984.

Tornado deaths and injuries, by year. Table 3 shows the distribution of tornado deaths and injuries by year and month for the 1950–96 period. As expected, the distribution varies greatly from year to year as a function of the number of tornadoes and the many deaths that can result from single storms or outbreaks. Figure 31 also shows the number of deaths by year from 1863 to the present. The year of the New Richmond tornado clearly stands out from other years.

Spatial distribution of "killer" tornadoes. Figures 32 and 33 show the paths of killer tornadoes for the periods 1863–1949 and 1950–96. These storms are in general better documented than most nonfatal older tornadoes, and it is usually possible to find enough information to recreate a tornado track, even for the earliest storms. It is interesting to note the shift of tornado tracks between the two periods: The earlier storms are clearly more focused on the southwestern half of the state; storms in the modern period are more widely scattered, but few are found in the southwest. This difference is not easy to explain from the record. However, Grazulis (1993) showed this shift can be seen in tracks of all significant tornadoes, and not just killers. It may also reflect changes in settlement patterns and outside work activities, where humans are most vulnerable. Figure 32 may also help to explain the perception of the region near St. Croix County as a local tornado alley because many deaths were recorded in the area in early Wisconsin history.

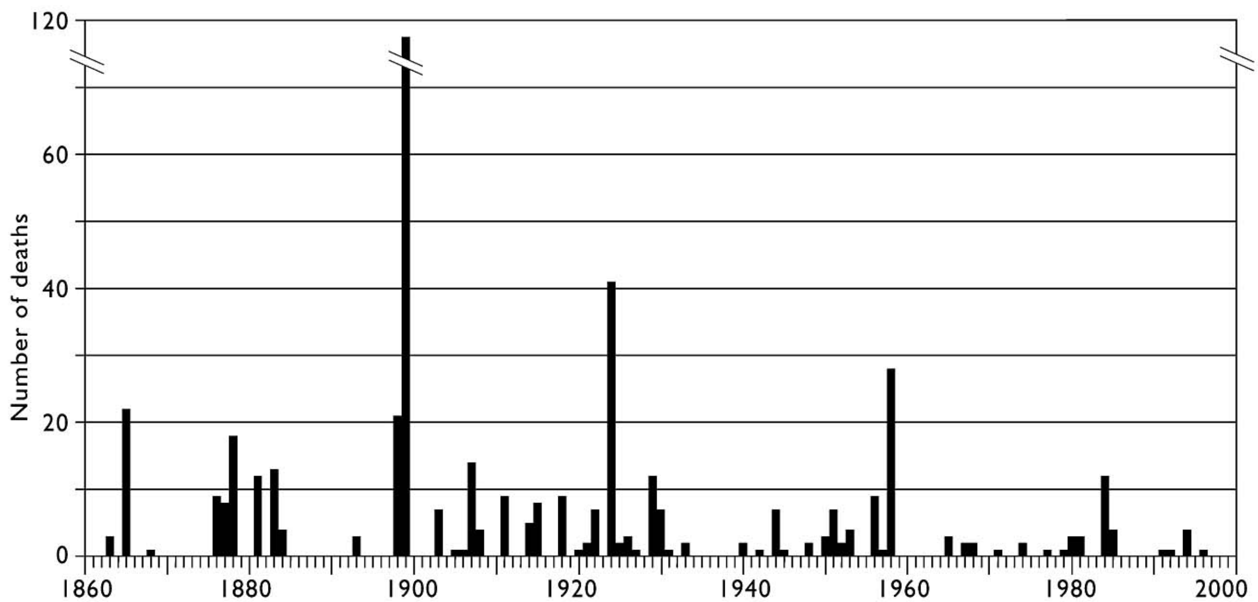

Figure 31. Number of tornado deaths, 1863–1996.

Table 3. Number of tornado injuries and deaths, 1950–96 (i=injuries, d=deaths; only nonzero values given. Plus sign (+) indicates most recent year of several occurrences; updated through December 1996.

	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Annual	
Year	i	d	i	d	i	d	i	d	i	d	i	d	i	d	i	d	i	d	i	d	i	d	i	d	i	d
1950	.	.	.	.	.	.	.	.	.	.	50	3	.	.	.	.	9	2	.	.	.	.	.	.	59	5
1951	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13	7	.	.	.	.	.	.	13	7
1952	.	.	.	.	.	.	.	.	.	.	6	2	.	.	.	.	.	.	.	.	.	.	.	.	6	2
1953	.	.	.	.	.	.	.	.	39	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	39	4
1954	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0
1955	.	.	.	.	.	.	1	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	0
1956	.	.	.	.	.	.	57	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	57	9
1957	.	.	.	.	.	.	1	1	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	5	1
1958	.	.	.	.	.	.	.	.	5	.	172	28	.	.	4	.	.	.	.	.	.	.	.	.	181	28
1959	.	.	.	.	.	.	.	.	6	.	.	.	3	.	.	.	3	.	2	.	.	.	.	.	14	0
1960	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0
1961	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	0
1962	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	0
1963	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13	.	.	.	.	.	.	.	.	.	13	0
1964	.	.	.	.	.	.	.	.	28	.	2	.	2	.	34	.	4	.	.	.	.	.	.	.	70	0
1965	.	.	.	.	.	.	84	3	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	94	3
1966	.	.	.	.	1	.	.	.	3	.	.	.	12	.	2	.	.	.	.	.	.	.	.	.	18	0
1967	.	.	.	.	.	.	.	.	.	.	.	.	12	.	5	2	.	.	.	.	.	.	.	.	17	2
1968	.	.	.	.	.	.	.	.	.	.	2	.	.	.	10	2	.	.	.	.	.	.	.	.	12	2
1969	.	.	.	.	.	.	.	.	.	.	8	.	4	.	153	.	.	.	.	.	.	.	.	.	165	0
1970	.	.	.	.	.	.	6	.	1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	8	0
1971	.	.	.	.	.	.	.	.	5	.	5	.	2	1	.	.	12	.	.	.	1	.	.	.	25	1
1972	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	3	0
1973	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	2	0
1974	.	.	.	.	.	.	54	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	54	2
1975	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	6	0
1976	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0
1978	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	2	0
1979	.	.	.	.	.	.	.	.	.	.	9	.	3	.	1	1	.	.	.	.	.	.	.	.	13	1
1980	.	.	.	.	.	.	22	.	.	.	4	.	27	3	.	.	.	.	.	.	.	.	.	.	53	3
1981	.	.	.	.	.	.	59	3	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	62	3
1982	.	.	.	.	2	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	0
1983	.	.	.	.	.	.	.	.	.	.	.	.	10	.	.	.	.	.	.	.	.	.	.	.	10	0
1984	.	.	.	.	.	.	39	3	.	.	202	9	.	.	.	.	.	.	3	.	.	.	.	.	244	12
1985	.	.	.	.	.	.	.	.	3	.	42	2	.	.	36	2	.	.	.	.	.	.	.	.	81	4
1986	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	0
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1994	.	.	.	.	.	.	.	.	3	.	.	.	2	.	50	4	.	.	.	.	.	.	.	.	55	4
1995	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1	0
1996	.	.	.	.	.	.	.	.	.	.	.	.	13	1	.	.	.	.	.	.	.	.	.	.	13	1
Total	0	0	0	0	8	1	329	21	115	4	556	44	130	6	357	12	45	7	6	0	1	0	0	0	1547	95
Avg	0	0	0	0	0	0	7	0	3	0	12	1	3	0	8	0	1	0	0	0	0	0	0	0	33.3	2.0
Max	0	0	0	0	5	1	84	9	39	4	202	28	30	3	153	4	13	7	3	0	1	0	0	0	244	28
Year					1991	1991	1965	1956	1953	1953	1984	1958	1992+	1980	1969	1994+	1951	1951	1984		1971				1984	1958

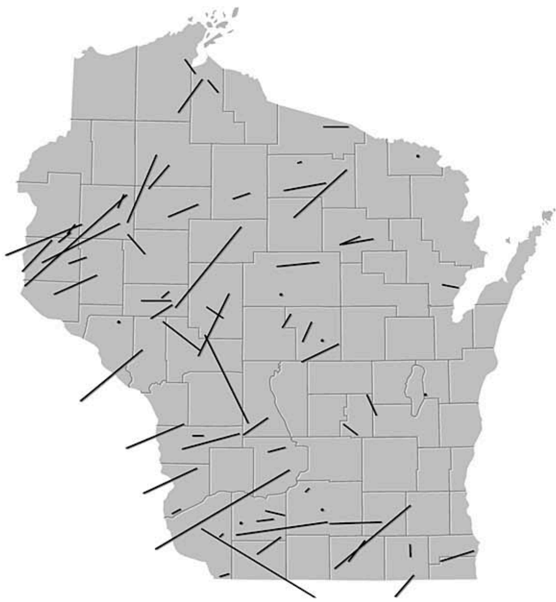

Figure 32. Paths of historic killer tornadoes before 1950.

Figure 33. Paths of killer tornadoes, 1950–96.

TORNADO SAFETY RULES

Over time, tornado safety rules have changed significantly due to increased understanding of how tornadoes damage buildings and inflict injuries. Because of this, it is useful to remind ourselves of actions to take and avoid when threatened with severe weather.

First and foremost, plan where you are going to find shelter *before a tornado threatens*. Every home, business, school, and church should have designated shelter areas. Shelter areas should be well marked, and everyone should be reminded at the beginning of each tornado season where they are so that people can get to them quickly when severe weather hits. The choice of shelter areas is described later in this section.

Determine how you will find out if a tornado or severe weather threatens *before* conditions are ripe for tornado activity. Many injuries and deaths from severe weather could have been prevented if people had responded quickly to television and radio warnings.

If your community has a siren system, learn what it sounds like and listen for it, especially when conditions seem favorable or a watch is posted. Most communities test their sirens weekly during tornado season. If there is no siren system, stay tuned to the radio or television for posted watches and warnings. Remember, power may go out before a warning can be issued, so be prepared with portable battery-powered devices that can be carried to the shelter with you. If the siren goes off and then stops, do not assume that means the tornado threat is over because power loss may have interrupted the siren operation.

A National Oceanic and Atmospheric Administration (NOAA) Weather Radio (NWR) is an especially good investment for tornado safety. The National Weather Service broadcasts watches, warnings, advisories, and other forecast information 24 hours a day by nine radio transmitters in Wisconsin and six others near the Wisconsin border. A map of frequencies for these stations is shown in figure 34. The frequencies range from 162.475 to 162.55 MHz and require a special radio receiver. Weather radios can be purchased at many electronics stores. Some of these radios can be set to receive a 10-second tone alarm when warnings are broadcast, alerting you to imminent severe weather. However, do not depend on sirens, radio, or television broadcasts to protect yourself. Sometimes severe weather develops so quickly that warnings

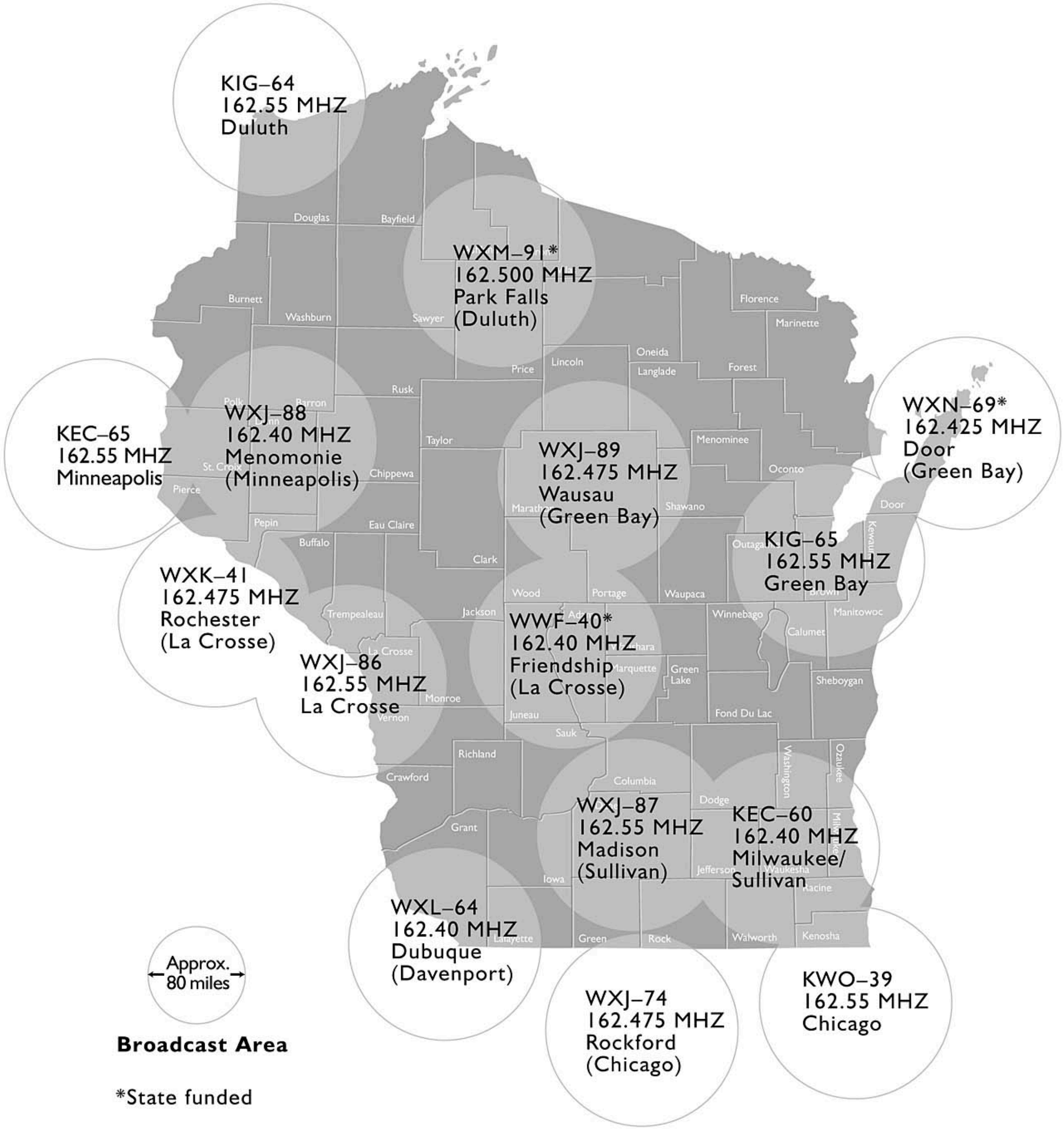

Figure 34. Locations and frequencies of NWR radio stations in and near Wisconsin.

are not issued until after significant damage has already occurred. Even with the improved capabilities of the National Weather Service, warnings are still broadcast only about half the time.

If conditions are threatening, do not take chances, but move people to a safe place until the danger of severe weather is over. Some warning signs to look for include rotation of the clouds above you, large hail, green skies (which may be due to the presence of the hail, not the tornado itself), and a loud sound like a freight train, jet engine, or swarm of angry bees. *Act quickly!* Even in open country, you may have less than a minute from the time you spot the tornado until it hits because of low visibility due to heavy rain and hail.

Choose a safe place inside to take cover in severe weather. Usually, the lowest floor of the building is the best choice. Traditionally, people were told to move to the southwest corner of the basement to find the best tornado shelter. Studies now show that the southwest corner may be the *least* safe place during severe weather. Because many tornadoes move from southwest to northeast (see fig. 23), walls usually collapse into the southwest corner when a tornado hits a house. But the northeast corner is not necessarily safer because debris from the house can be blown into that corner as the tornado moves overhead. The best place to hide in a basement is under a heavy table or stairwell, wherever it is located.

If you do not have a basement, then you should look for shelter on the first floor in rooms or closets away from the most likely path of the tornado. Because most (but not all) tornadoes come from the southwest, you should avoid western and southern exposures unless they are heavily reinforced. Usually, a centrally located closet or bathroom is the best choice. You can further protect yourself by kneeling and covering your head with your arms or a padded object like a blanket or mattress. Some scientists believe that bathrooms offer an extra level of protection because of the reinforcing effect of plumbing. Windows should be avoided. Interior hallways may be safer unless a door or window is at the end, which can open and create a wind tunnel in the hallway.

If you live in a mobile home, go to a reinforced shelter or building. *Do not stay in a mobile home in severe weather!* Because they are light and lack a sturdy ground attachment, mobile homes are deathtraps for anyone who stays inside. More than 37 percent of all tornado fatalities nationwide occur in mobile homes.

If you are in an auditorium, gymnasium, barn, or large, open room, find a smaller, enclosed room to provide you with shelter. Do not stay in any area with an open floor plan and thinly supported roof because damage is generally higher in these unreinforced areas.

If you are outside and no shelter is near, get to the lowest place you can find. Lying in a ditch or culvert below the level of the ground will protect you from the worst of the wind and flying debris (and lightning, too), although it is possible that wreckage could still land on top of you. Keep in mind that ditches may sometimes fill with water when rainfall is heavy and be alert for rising water levels. Some people have used the girders beneath highway overpasses as shelter, but they are not always safe. Strong tornadoes have destroyed roads and bridges in the past.

If you are in a car, *get out* and get to a building or ditch. *do not* try to outrun the tornado unless you have a very clear understanding of where the tornado is and where it is moving. Tornadoes have been known to move as fast as 60 miles per hour, and your car may not be able to outrun it on busy streets. Although most people are killed by flying debris, many individuals have also been killed in cars when they were lofted into the air and slammed to the ground or rolled over; some of these people were trying to outrun the tornadoes that ultimately killed them. However, if you are out in the open on roads with little traffic and know where you and the tornado are moving, driving away from the tornado, preferably at a right angle to the storm path, may be an acceptable option.

Do not open the windows in houses to "equalize" the pressure. Engineers have shown that almost all of the damage from tornadoes is caused by high winds and flying debris, not pressure differences. Opening a window may reduce your walls' structural integrity, increasing the chance of damage by allowing high winds into the house, where they can push up on the roof and back walls. It may also cause rain damage to the interior and to electrical appliances where no damage might otherwise have occurred. Similarly, keep the garage door closed to provide some counterforce to the wind and to prevent tools and vehicles from being blown out as deadly missiles. As many tornado experts say, "if the tornado wants your garage door or window opened, it will do it for you." If your windows are already open, however, then don't take the time to close them because they may break as you are trying to close them.

Do not count on local features like hills, rivers, or lakes to protect you. There is no evidence to support the idea that the confluence of rivers or the presence of hills is enough to protect you from a deadly tornado. Just because a tornado has not struck a particular location yet, there is no reason to think that it will be missed the next time severe weather hits. By the same token, don't assume that some other place will always be hit (a local tornado alley, for example). Although some areas do tend to get hit more often for a few years than others (for example, see fig. 10), in the long term there is no reason why one area should be hit more often than others nearby.

One example of a myth about protection from local features in Wisconsin is that Lake Mendota in Dane County prevents tornadoes from forming downwind of the lake. The "arguments" for this are unclear, but presumably the premise is that the lake somehow disrupts the severe thunderstorms as they pass over, destroying their tornadic circulation. However, this myth is not borne out in maps of tornado paths in Dane County, where slightly more tornadoes seem to have been spotted downwind of the lake than upwind (fig. 35), although they are more or less randomly scattered across the county. The fact that the area within Madison's city limits has not been hit by a long-path tornado in recent years is no predictor of things to come, nor is the concentration of tornado paths some people see in the southeastern part of the county. As part of the larger state map, these variations disappear. Similarly, arguments that Prairie du Chien or La Crosse are protected because they are located at the confluence of rivers should not be taken seriously.

Videotaping is not recommended. Some "eyewitness" television shows have played spectacular video footage of close encounters with tornadoes taken by amateur photographers. What they don't tell you is that the videographers were many times so foolhardy in their attempts to capture marketable footage of severe weather that they didn't realize how much danger they were in. In a few cases, the photographers have been killed by the storms they taped, either by debris from the tornado or by lightning that hit nearby. Don't take unnecessary risks. Leave the photography to the experts and get to a place of safety.

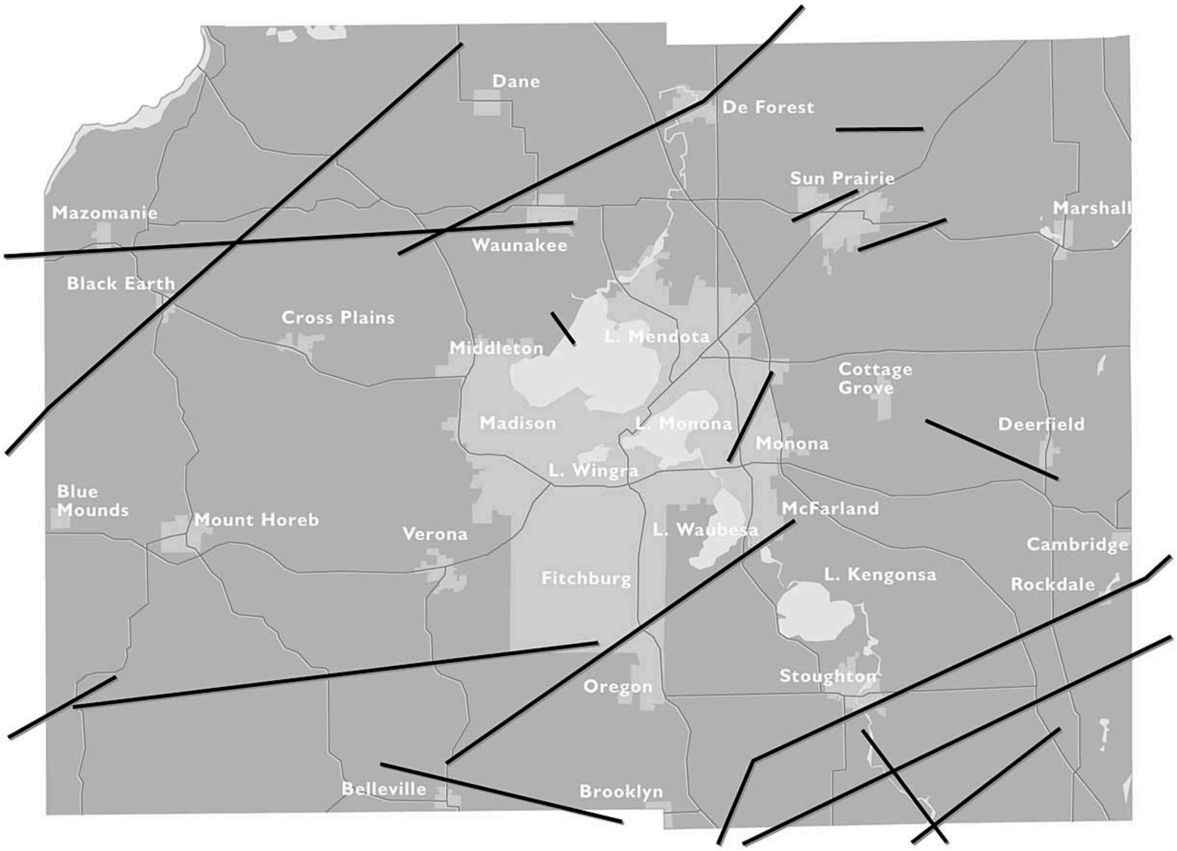

Figure 35. Paths of tornadoes in Dane County, 1950–96.

CONCLUSIONS

Tornadoes are an exhilarating as well as terrifying part of the wide range of weather phenomena seen in Wisconsin. They provide evidence of the power and majesty that nature can display, but also present a warning not to treat the atmosphere lightly. Their paths highlight the broad characteristics of Wisconsin climate in ways that simple maps of temperature or precipitation cannot. As long as we avoid their dangers and treat them with a healthy respect, they can teach us about the wonderful state we live in.

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Wisconsin Counties
University of Wisconsin–Extension
Wisconsin Geological and Natural History Survey
0 20 40 60 miles
0 20 40 60 kilometers
Douglas
Bayfield
Ashland
Iron
Vilas
Burnett
Washburn
Sawyer
Price
Oneida
Florence
Forest
Marinette
Polk
Barron
Rusk
Lincoln
Langlade
Taylor
St. Croix
Dunn
Chippewa
Menominee
Oconto
Marathon
Pierce
Pepin
Eau Claire
Clark
Shawano
Door
Kewaunee
Buffalo
Trempealeau
Jackson
Wood
Portage
Waupaca
Outagamie
Brown
Manitowoc
Calumet
Winnebago
Waushara
Adams
Juneau
Monroe
LaCrosse
Marquette
Green Lake
Fond du lac
Sheboygan
Vernon
Crawford
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