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WIND ATLAS OF WISCONSIN

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Wisconsin Geological and Natural History Survey

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PREFACE

The measurement of wind is one of the most basic measurements in climatology. Wind speed and direction carry information about where the air affecting a region has come from, helping to characterize it by temperature, humidity, dustiness, and even the insect and air-borne chemicals blown with it. Recognizing this, climatologists have observed the wind in Wisconsin for more than 100 years at a few locations within the state. In fact, from the early 1890s, when widespread climate observations were first started, until 1948, each of the roughly 100 basic climatological stations reported prevailing wind direction as part of their regular monthly reports. Most of these records, however, were based on subjective observations and have never been put into digital form.

The study of wind received new emphasis in the early 1940s with the transfer of the U.S. Weather Bureau (now the National Weather Service) from the Department of Agriculture to the Department of Commerce. This move recognized the increasing importance of weather information to the transportation industry, particularly the fledgling airline industry. Many long-term wind observation sites were moved from within cities to their present locations at airports outside of the city limits. Because the data about wind speed and direction collected from the relatively rough urban stations in the cities cannot be directly compared to that collected from the open, grassy fields of the airports, all data used in this atlas are from 1948 or later.

Today, the importance of accurate wind observations is being newly recognized by many different groups, including those who study wind power, air pollution, agriculture, forest fires, and highway transportation. As a result, many new networks of automated weather sensors have sprung up across the state. The National Weather Service is also in the process of switching its observations from human to automated surface-observing systems as part of its modernization effort and is expanding its coverage of wind observations to many regions that had no climatological wind information available in the past. Although the new networks employ different instrumentation and observation techniques than were used previously, in the future they may provide a wealth of additional information about the spatial character of wind in Wisconsin.

INTRODUCTION

The Wisconsin State Climatology Office receives thousands of requests each year for climate-related information from businesses, agriculturalists, lawyers, insurance companies, scientists, students, and private citizens. Of all the types of weather data requested, wind information is probably the hardest to obtain. This atlas was developed as an attempt to make climatological wind data for Wisconsin more widely available and to describe wind patterns in the context of the larger-scale atmospheric circulation that affects temperature and precipitation.

In this atlas, I describe the causes of wind, how it is affected by regional and local conditions, and how it can be used in the siting and construction of buildings. Monthly and annual wind characteristics are presented for 13 stations in and near Wisconsin. Monthly information includes wind-rose maps, statistics on average and extreme winds for each month, and brief descriptions of how the wind varies with the hemispheric weather patterns. I have also included an annotated bibliography of documents that contain related information.

PHYSICAL CHARACTERISTICS OF WIND

Why does the wind blow?

In the simplest terms, wind is the atmosphere's attempt to equalize atmospheric pressure everywhere on the surface of the Earth. (*Pressure* is the force of air pushing on a surface and is most commonly thought of as the weight of air pushing down on the ground, although it actually pushes in all directions.) Pressure differences can occur because of variations in temperature, humidity, or elevation from one place to another. As the atmosphere attempts to adjust to these regional differences, air flows from one place to another. This flow of air is what we commonly think of as *wind*.

At sea level on the surface of the Earth, the entire atmosphere rests on the ground at an average weight of 14.7 pounds per square inch. As you go higher up in the atmosphere, the pressure decreases because the total weight of air above you is less. The atmosphere below you (if you are in an airplane, for example) also pushes up, producing a buoyant force much like that of water. If you climb a mountain or go up in a balloon or airplane, you are moving to an area of lower pressure. But the air does not flow upward because the pressure force upward is balanced by gravity, which pulls the air back toward the Earth. In most of the atmosphere, we know that vertical wind speeds are small because the net force is slight. The main exception is in areas of intense thunderstorms, where other forces can come into play. There, updrafts and downdrafts of 40 miles per hour or more are often observed.

In the horizontal direction, pressure differences from one place to another are mainly caused by differences in heat-

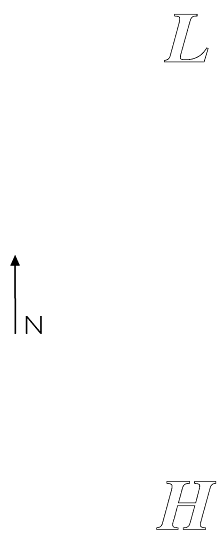


***Figure 1.** Wind patterns around low- and high-pressure centers.*

ing, which may be produced by sinking of air east of the mountains, the presence of a heated surface such as the Gulf Stream in the Atlantic Ocean, or condensation of water vapor to form rain. Changes in surface pressure can also be caused by shifts in the total weight of the atmosphere above the surface. These shifts can be produced by jet streams or other upper-air disturbances that move through the atmosphere.

But pressure differences alone do not determine the final direction of wind flow. We must consider the effects of two other forces that act with pressure differences in the horizontal direction. These forces are the *Coriolis force* and *friction*.

If we lived on a planet that did not rotate, the Coriolis force would not exist. However, our world does rotate, and the result is a “pseudo-force” that causes the air to move toward the right of the compass direction of motion in the Northern Hemisphere and toward the left in the Southern Hemisphere. Meteorologists call it a pseudo-force because it is not a force in the physical sense, but is merely an effect of planetary rotation. The deflection of the wind to the right depends on the distance from the equator: At the equator, the Coriolis force is zero; the highest Coriolis force is farthest from the equator. Because the Coriolis force is an integral part of the formation of hurricanes, no hurricanes can form within about 5^{o} of the equator, where the Coriolis force is very weak.

In addition, friction at the surface of the Earth slows down the flow of air. The ground presents a rough surface for air molecules to rub against, reducing their speed. The rougher the surface, the more the molecules are slowed. That is why winds inside a forest are lighter than winds in an open area, where friction is weaker. Winds on or near water can be especially fast because the water surface provides little friction.

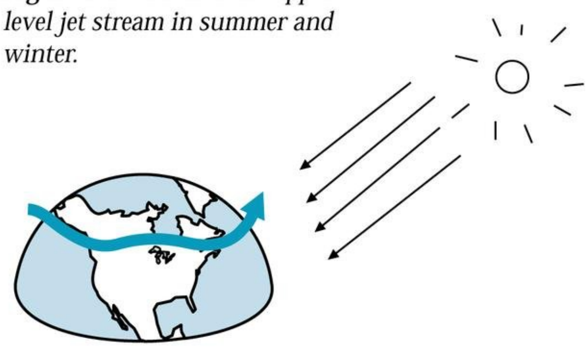
The pressure differential and Coriolis and frictional forces act together to produce wind that blows in characteristic patterns around areas of low and high pressure. In figure 1, the flow of air around a low-pressure area at the surface is shown by arrows. Winds around lows in the Northern Hemisphere tend to rotate counterclockwise and blow slightly toward the area of lowest pressure. This is a result of the balance of the pressure gradient and the Coriolis and frictional forces. In high-pressure areas, the winds blow clockwise and tend to blow outward away from the center of highest pressure.

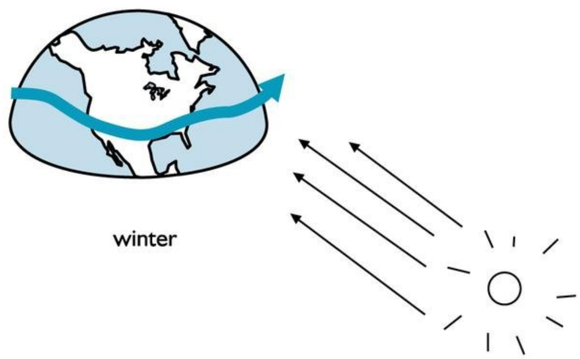
Large-scale influences of atmospheric patterns on Wisconsin

High- and low-pressure centers generally move across the United States from west to east on characteristic paths that change over the year. The shifting movement of the low- and high-pressure areas across Wisconsin is the key to understanding how the winds change over the year. The path that pressure centers follow is called the *storm track*.

Storm tracks are linked with a strong wind several miles up in the atmosphere; this wind is called the *jet stream*. The general location of the storm track moves north in spring and summer as the atmosphere, oceans, and land in the Northern Hemisphere warm with the sun and retreats south in fall and winter (fig. 2). This generalized storm track moves through Wisconsin twice a year—in middle to late spring as it passes to the north, and in early fall when it passes to the south again.

Figure 2. *Position of the upper-level jet stream in summer and winter.*





In winter, when the biggest temperature gradients are south of Wisconsin, low-pressure areas also pass to the south along the primary storm track. During this season, much of our wind has a northerly or easterly component, especially when the lows are nearby. (You can see this by looking at the wind direction on the north side of the low-pressure center in fig. 1.) In the summer, lows usually pass north of Wisconsin, and our wind tends to be from the south and southwest, bringing warm and humid air into the region from the Gulf of Mexico and the desert Southwest. In the weeks when the storm track (and the centers of low pressure) is directly over Wisconsin, the winds are stronger and change more frequently.

In theory, a single storm track moves with the steepest hemispheric gradients of temperature through the year. In reality, however, storms tend to travel along one of several preferred paths, which can change from one season to the next. Figure 3 shows the monthly variation of common tracks of low-pressure areas and the regions from which the lows come. Generally, lows that affect Wisconsin develop at one of several locations in the lee of the Rocky Mountains. These lows are referred to colloquially as Alberta clippers, Colorado lows, and (Texas) Panhandle hooks because of their characteristic speeds and paths.

Local influences on winds

Because temperature can cause variations in air density, the wind at particular locations can also be affected by any local factor that causes variations in temperature. This can include the effects of lakes and the effects of hills and valleys.

Lake breezes. Lake breezes, especially along the Great Lakes coastlines, play an important role in determining local climate near the shore. Because water heats and cools at a slower rate than land, lakes are cooler than the nearby land in spring and summer and are warmer than land in fall and winter. Warm air is less dense than cold air; as a result, the differ-

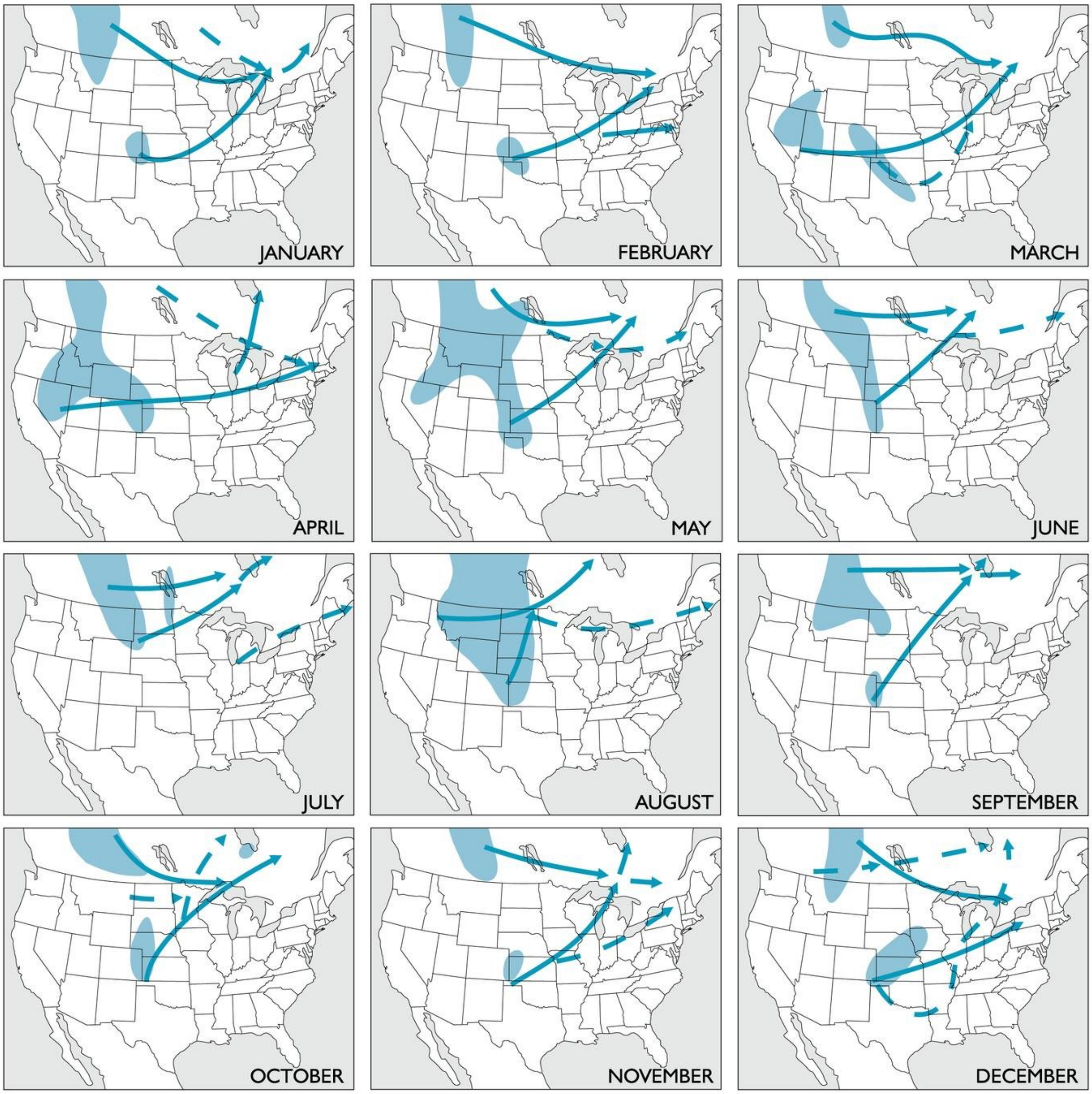
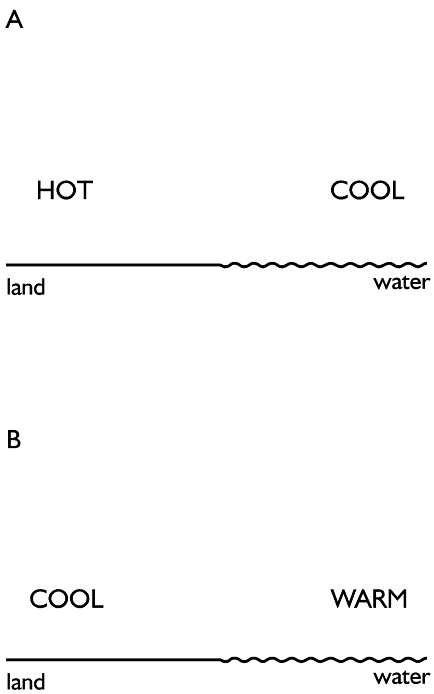


Figure 3. *Preferred paths of low-pressure centers that affect Wisconsin, by month. Solid lines represent primary paths; the dashed lines, secondary tracks. The shaded areas are regions where the lows develop. Adapted from Whittaker and Horn, 1982.*

Figure 4. *Vertical air flow near the shore of a large lake in summer. A: Day. B: Night.*



ence in heating between land and water leads to a local pressure difference. This can drive local winds that are distinct from the large-scale wind patterns associated with high- or low-pressure centers. This is especially true in early summer, when the heating of land is most intense.

Figure 4a shows the vertical pattern of wind that occurs during the day along the lake shore. The cool air over the lake is denser than the warmer air over land, and so a difference in pressure between lake and land is produced. A local "sea breeze" then flows onshore from the lake to equalize the pressure variation. This breeze off the lake is cooler than the air over the land, and provides cooler conditions near the shore. The cool conditions are especially noticeable in Milwaukee in spring, when the lake breeze blows very cold air off Lake Michigan.

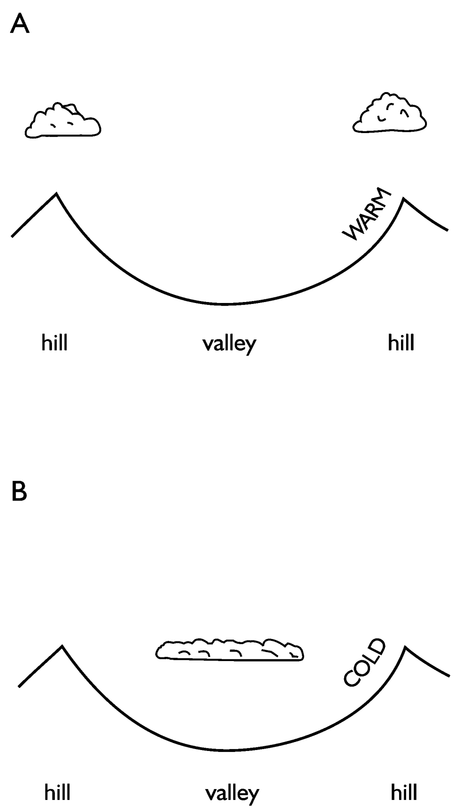
Rising heated air over the land and sinking cool air over the lake help set up a closed circulation that is completed by air flowing from land to lake at higher levels in the atmosphere. This high-level flow can sometimes be seen in plumes from tall smokestacks at the shoreline. The entire circulation usually exists only within a few miles of the shoreline.

Figure 4b shows the reversed circulation that occurs at night in the summer months. Usually the land cools off rapidly after nightfall in summer, reversing the pattern of warmth and cold that exists during the day. A corresponding *land breeze* flows from land to lake at night, although it is usually not as strong as the daytime lake breeze is.

Effects of hills and valleys. Differences in the heating of ridges and valleys can also lead to density variations, which drive local winds. During the day, high ridgetops can become much warmer than surrounding slopes, causing the air to become locally less dense. The warm air rises (fig. 5a) and is replaced by air flowing up the valley sides. Again, a closed circulation develops: Air rises over the hills and sinks in the valleys. The rising air is often revealed by lines of clouds that form along the ridges during the day, with clear valleys between. This up-valley wind is called *anabatic wind*.

At night, the ridges cool faster than the valley floors. In response to the force of gravity, cold, dense air formed along the ridgetops flows down the sides of the valleys and pools at the bottom of the valleys. As this cold air flows into a valley, it pushes the warmer valley air up, creating a local closed circulation in the opposite direction from that during the day (fig. 5b). This air flow is called a *katabatic wind*. In its most extreme example, on Antarctica, katabatic wind flow off the interior plateau of the continent can reach 60 mph or more in a shallow layer only 10 to 20 feet deep. Although katabatic winds in Wisconsin are not nearly as strong, they can lead to differences in temperature of several degrees or more across

Figure 5. Vertical air flow near hills and valleys. A: Day. B: Night.



a valley. Cold ridges and valley floors can retard plant growth; the mildest conditions are usually found on the valley sides, especially on the slopes facing the sun. This is especially noticeable in the Driftless Area of southwestern Wisconsin and in hillier areas of northern Wisconsin. However, it can also be seen in places in Madison; for example, the official station at the airport is located in a low-lying area and often measures low temperatures several degrees colder than other southern Wisconsin stations.

Hills and valleys can also cause mechanical alterations in wind patterns. The orientation of the valleys can produce preferred directions for wind flow, especially in the largest valleys. Winds at La Crosse, for example, are strongly affected by its location in the Mississippi River valley, with a strong preference for up-valley or down-valley flow.

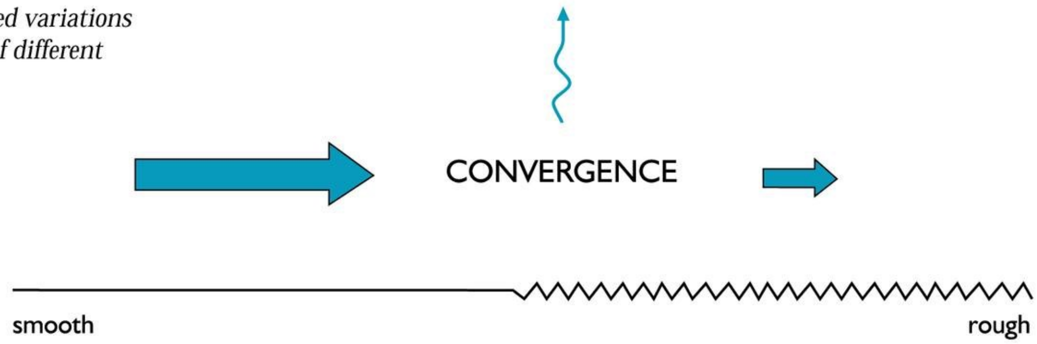
Other local effects. Other regional variations can also influence local wind patterns. Differences in surface roughness between grasslands, forests, and lakes can affect the frictional force. These differences may cause wind to "pile up" in some locations because of abrupt changes in wind speed resulting from frictional differences. This increases the pressure of air at the spot where the air converges. For example, figure 6 shows the effects of air moving from a smooth surface (a lake, perhaps) to a rougher surface (grass or forest). On the smooth surface, friction is low and the wind speed is relatively high. Over the rougher surface, increased friction immediately causes the air to slow down, leading to a *convergence* of air near the boundary. Because the air can't go down into the ground, it must rise to reduce the air pressure, leading to a local circulation that is not driven by temperature, but by differences in surface characteristics. In traffic, we get a similar convergence of cars when fast-moving cars enter a region of slow-moving traffic. The resulting increase in density causes massive convergence of vehicles where the speed changes, leading to traffic jams.

Wind conditions and air pollution

Because air carries the particles and gases that make up air pollution, the wind is an important factor in the development and dispersion of pollutants. Regional and local factors must be considered in deciding where to place smokestacks so that pollutants will be properly diluted and not blown back into the communities from which they were emitted.

The days that have the highest levels of pollution generally are days that have low wind speeds, such as those that are found in the center of high-pressure areas. The low wind speeds prevent cleaner air from above from mixing with the polluted air near the ground, allowing toxins to build up in the surface layer of the atmosphere. These conditions are ex-

Figure 6. *Wind-speed variations caused by surfaces of different roughness.*



acerbated by high temperatures and sunny conditions, which help to develop high concentrations of ozone and other noxious gases. The lake breezes near the Great Lakes shorelines can also affect pollution concentrations, increasing pollution levels at some locations and diluting it at others. The daily evolution of the lake breeze as the land heats up may also allow pollutants to blow offshore during the day, only to return later as the breeze reverses. (Pollution information is collected in Wisconsin by the Department of Natural Resources Bureau of Air Management, 101 S. Webster Street, P.O. Box 7921, Madison, Wisconsin, 53707, 608/266.7718.)

MEASUREMENT OF WINDS

Instruments

The measurement of wind requires taking two pieces of information: speed and direction. Therefore, most wind-measuring devices have two sensors—an *anemometer* to measure wind speed and a *wind vane* to measure wind direction. (Some more sophisticated instruments use a different device that measures wind speed from each of three mutually perpendicular directions and uses mathematical techniques to calculate the total wind speed and direction, but these specialized devices will not be covered further here.)

Anemometers ascertain wind speed by measuring the movement of air past a sensor. The most common anemometer used is the *cup anemometer* (fig. 7). Cups exposed to the wind catch the wind and rotate around a central pole as the wind pushes against them. The faster the wind blows, the higher the force of the wind on the cups, and the faster the device rotates. In principle, any instrument that has uniform and evenly spaced cups can measure wind speed if properly calibrated, but in reality a great deal of engineering has gone into reduction of turbulence and friction around the cups. This is especially important at low wind speeds, when engineering details can significantly affect the accuracy of the wind measurements.

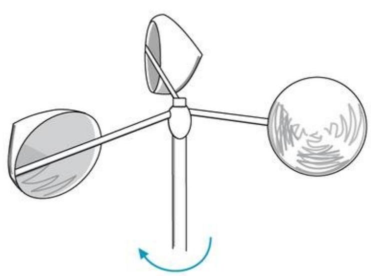


Figure 7. *Cup anemometer.*

Other anemometers use the *Bernoulli Principle* to measure wind flow across a small opening. In this method, a horizontal wind blows across a vertical pipe, decreasing the pressure in the pipe. The faster the wind flows across the pipe, the lower the pressure inside the pipe is. This difference can be measured and converted into wind speed. However, in this atlas, all data have been taken using cup anemometers.

Wind vanes measure the wind direction by providing a flat surface for the wind to push against. If the wind is pushing harder on one side of the surface than on the other, the vane will rotate in the direction of the wind until the force on both sides of the flat surface equalizes. An arrow or other pointer on the wind vane indicates the direction of the wind.

In weather observations, wind direction always indicates the direction *from which the wind is blowing*. Therefore, a north wind means that the wind is blowing from the north toward the observer. A southeast wind blows from the southeast toward the northwest. Temperatures and humidity tend to be carried with the wind; therefore, the prediction of a south wind usually means warmer, more humid conditions because temperatures and humidity are highest in the south in the United States. In Wisconsin, however, sometimes a southwest wind can mean drier conditions if the wind is blowing from the desert Southwest, especially in the summer.

Units

Wind speed is measured in units of length per unit of time. In the United States, wind speed is most commonly given as miles per hour. However, another unit, the *knot*, is often used by the military and airlines. One knot equals 1 nautical mile per hour, or 1.15 standard miles per hour. In international units, wind speed is almost always measured in meters per second. One meter per second is 2.24 standard miles per hour. This atlas uses miles per hour (mph) as the primary unit of wind speed.

Average winds versus gusts

Wind observations can cover different periods of time, from instantaneous measurements of wind to averages over a day or more. Measurements of *wind gusts* are considered to be instant snapshots of the wind and are usually reported as the maximum gust in a 1 minute to 1 day period. Information on gusts is often used in engineering to determine the maximum wind a structure might have to withstand over a short period of time.

Mean winds are averages of wind over a time interval chosen by the person using the information. Usually, winds are averaged over 5 minutes, 1 hour, or 1 day, although other periods can be used. In general, the term *average wind* is used to describe an average of all wind speeds within a given time, regardless of direction. The *resultant wind* is an average calculated using vector algebra, which means that speed and direction are used to calculate the net wind for the period. The *prevailing wind* is the most frequently observed wind speed and direction.

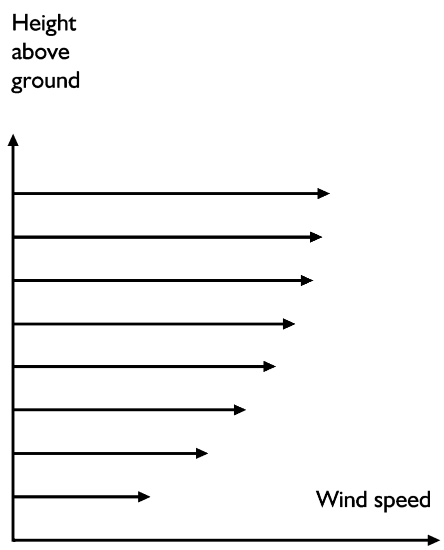
The difference between the types of mean wind is easier to understand if you consider a simple example. Suppose that at the beginning of the day you release a balloon that stays at a constant height above the ground and watch its path during the day. If the wind were blowing at a constant speed of 10 mph all day, but for 12 hours, it was blowing straight from the north and for the other 12 hours, it was blowing straight from the south, then the *average* wind speed that day would be 10 mph, but the *resultant* wind would be 0 mph because the wind from the north would exactly cancel the wind from the south. At the end of the day the balloon would have returned to its original spot, and there would have been no net change of position over time. You could not determine a *prevailing wind* on this day because the frequency of wind from the north equaled the frequency of wind from the south.

Variation of wind with height

Because friction is one of the major forces that acts on the atmosphere, the presence of a rough surface can greatly affect the speed (and to a lesser extent, the direction) of the wind. In the atmosphere, the greatest source of friction is the surface of the Earth. Because friction slows down the air near the ground, winds in the atmosphere tend to increase with height.

In general, wind speed increases logarithmically with height. Figure 8 shows a typical profile of wind speed as a function of distance above the ground. The greatest changes in wind speed are near the surface, where the effects of friction are large. Far from the surface, wind speed is nearly constant with height. The rate of the change of speed with height depends on the roughness of the surface.

Figure 8. *Variation of wind speed in relation to height.*



This factor becomes important in comparisons of wind information at different sites. National Weather Service (NWS) stations nominally use a standard instrument height of 10 meters (33 feet) for their wind instruments. That makes comparisons of wind from one site to the next relatively straightforward. Users should note, however, that heights of wind sensors at many NWS sites vary from the stated standard and sometimes change without documentation. Other types of stations use 2-meter or 10-foot heights for their instruments. To compare data from sites that have the instruments at different heights, you must first convert the wind data to a common height and then compare them. This conversion can be tricky if the surface characteristics are not well known. Because of this problem, this document includes only National Weather Service station information.

WIND AS A COMPONENT OF CONSTRUCTION AND ENERGY USE

How winds affect energy use and placement of windows

The flow of air around obstacles such as buildings, combined with the effects of sunshine, can greatly affect the local temperature and wind conditions around the obstacle. Careful builders take local winds into account when they design and situate new houses and industrial buildings. Including the effects of wind and sun is especially important when designing buildings that are energy efficient.

Energy escapes from buildings in several different ways. One way is called *radiational cooling*, which is caused by flow of energy in the form of infrared light to the outside through windows and, to a lesser extent, walls and roof. The loss of energy causes the inside of a building to cool. *Radiational heating* is caused in the summer months by the sun shining through windows on the south side of a building. The air inside houses can also be heated by sunlight reflected from driveways and by direct heating of the roof and sides of the house. Heating due to radiation can be reduced by planting deciduous trees on the south side of the house, which shade it in the summer months but allow sunshine to heat the house in the winter. Radiational cooling in the winter months can be reduced by using special reflective materials on the windows to reflect the infrared waves back into the house instead of allowing them to escape through the window.

A second way that energy escapes from buildings is by the process called *convection*. Convection is the process of transferring energy by physically moving it away from the source of heat. The air flowing past a house can whisk heated air near the house away, causing a loss of heat from the house. If a house is not well insulated, a significant amount of heat can escape from the inside of the building and will be carried away by the wind blowing around the structure. This is especially true if the house is drafty and allows wind from the outside in (and then also allows inside air out). Additional heat is lost when energy is also radiated out through the windows.

In Wisconsin, the coldest winds usually blow from the northwest in the winter months. Windows that are not well insulated can cause a double loss of heat if they are on the north side of the building because heat can be lost by radiation and convection. Many energy-efficient buildings limit the window area on the north side of the building to minimize their heating loss from the effects of the wind. Earthen berm homes often burrow their north sides completely into the ground to prevent energy losses caused by the north winds. Other people use planted wind breaks such as rows of trees to reduce the speed of the wind near their homes, which also reduces the energy loss. Many extremely well insulated (and expensive) windows are now available; their energy loss is nearly the same as that for walls, which may increase the use of north-facing windows in the future.

A third method of energy transfer is called *conduction*. Energy is conducted into or out of the house by direct heat flow from a hotter place to a colder place. The more insulation used in the walls and windows, the harder it is for heat to flow from the warm inside of the house in winter to the cold outside, where it can be carried away by the wind. Houses built in recent years are much more highly insulated than older houses, which has increased their energy efficiency tremendously. In fact, some houses are now so well insulated that they are encountering another problem: excess humidity. The water vapor that always leaked out of older houses readily is trapped in new homes that are superinsulated, leading to a buildup of humidity over time. A dehumidifier must be used to remove the excess moisture that accumulates.

Construction techniques to reduce wind damage

Photographs of destruction caused by tornadoes and hurricanes show how much damage the wind can produce. Wind damage to structures can be caused in several ways. First, the direct force of the wind can collapse windows and even walls if it is strong enough. Because the strength of the wind against a flat surface varies as the square of the wind speed, a doubling in the speed of the wind causes a quadrupling of the force of the wind against the structure. This makes a 100 mph wind four times as damaging as a 50 mph wind. Fortunately, these strong winds come quite rarely, and usually only last for a short time, but they can do enormous damage if they blow against a vulnerable structure.

A more frequent cause of severe wind damage to buildings is due to differences in air pressure from one side of the building to the other. At points where the air is flowing the fastest, the air pressure is the lowest (the Bernoulli Principle). It is this principle that allows airplanes to fly. Air flow over the curved surface of the wings causes a reduction in pressure on the top of the wings, which in turn causes the plane to lift upward. Similarly, air flow over the top of a roof can cause a reduction in pressure over the roof, leading to an upward force that tries to pull the roof off the building. If the roof is not well anchored to the house, or if the house is not well anchored to the foundation, the wind can lift up the roof or the whole house and smash it to the ground farther downwind. Once the structural integrity of the building is destroyed, the walls come down easily.

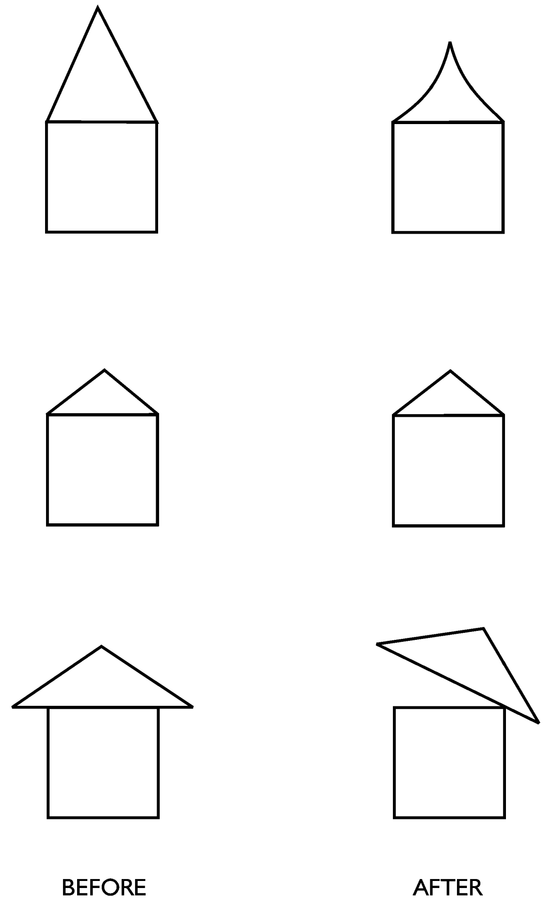
In spite of damage caused to buildings by differences in air pressure, it is not a good idea to try to reduce the pressure difference by opening windows in high winds. Years ago, people trying to protect their homes against damage from tornadoes were told to open their windows to equalize the pressure inside and outside of their houses. Now we know that most of the damage due to tornadoes results from the high winds associated with the storms, and not to pressure differences inside the funnel. Keeping the windows closed will help maintain the structural strength of the walls and windows and prevent the wind from rushing into the building and lifting off the roof from the inside as well as protect from flying debris.

Experience in tornado- and hurricane-prone areas has shown that some construction techniques can be used to reduce the damage from high winds. Bolting the house to the foundation and the roof to the walls of the house can provide enough strength to resist the upward pull of the roof in extremely strong winds. Even if the windows blow out, the damage to the building is much less severe. Pictures taken after Hurricane Andrew in 1992, for example, showed that houses in south Florida built with this technique were far more likely to survive hurricane winds than more cheaply built housing.

Another factor that affects the amount of wind damage is the shape of the roof (fig. 9). A steeply pitched roof provides a broad profile to the wind, which makes it easier for the wind to push the roof off the house. The higher roofs also catch the faster winds farther away from the surface of the ground than low roofs do. Low-pitched roofs provide a small profile to the wind and also minimize the effects of low pressure pulling off the roof. The presence of eaves also increases the effect of the wind by providing another surface for the wind to push against. Shallow eaves provide much less surface area for the wind to catch than wider eaves. The orientation of the roof with respect to the direction of the peak wind also plays a role in the damage the wind is likely to cause. A building that provides a small profile to the strongest wind and that smoothly channels the wind over the roof provides the best protection against wind damage.

Experience has also shown the danger of mobile homes in high winds. Most mobile homes are not well anchored to the concrete pads they rest on, and some have no tie-downs whatsoever. In addition, the gap under the mobile home provides room for the wind to push up on the trailer, lifting it up off its pad. This makes it likely that the mobile home will be lifted off its foundations in strong winds and rolled or thrown by the wind into other buildings. Structurally, mobile homes are not built to withstand unusually high winds, and may collapse even if they remain on their foundations. The best advice for combining mobile homes and high winds is to make sure that mobile homes are carefully tied down with multiple cables when they are moved into a park. If severe weather comes, ***do not stay in a mobile home!*** More than 37 percent of tornado fatalities occur in mobile homes. Go to a nearby shelter or reinforced building, or even in a low ditch protected from direct wind, rather than stay in the trailer.

Figure 9. Wind flow around houses with different roof profiles.



Wind power

Using the power of the wind to generate electricity gained favor in the early 1970s as a result of the oil embargo and high petroleum prices. As oil prices dropped, wind power became less attractive and was rarely mentioned. Now, renewed interest in clean sources of energy has increased the demand for information about wind and solar power.

Most people's image of a windmill is the familiar old slatted wheel on a rickety metal frame above a stock pond. In the traditional wind machine, the slanted blades on the wheel provided flat surfaces for the wind to push against. Modern wind machines instead may have blades that operate like airplane wings, creating differential pressure forces on the blade surface that cause the blade to move. In either case, the wind usually causes rotation around an axle, which drives a turbine that can generate electrical current. Because of the mechanical connections and the weight of the machinery, most wind generators need constant wind speeds of at least 10 mph before they can generate power. New designs are now lowering this threshold to allow generation at lower wind speeds. An example of a wind turbine is shown in figure 10.

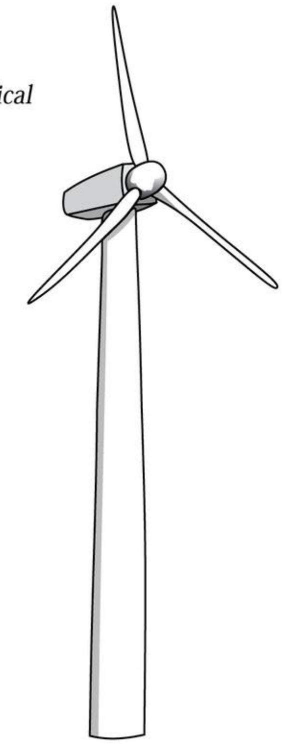


Figure 10. *A typical wind generator.*

Because wind turbines need higher wind speeds to work effectively, and because wind power varies as the cube of the wind speed, it is useful to look at the distribution of wind by speed category to determine how often the higher wind speeds occur. An area that has a higher percentage of strong and constant (but not extreme) winds is generally a better wind-power site because the equipment can generate power more often and more efficiently than a site with a lower frequency of high winds. Table 1 contains information about the frequency of wind speeds for several NWS stations in the Midwest. Rochester, in southeastern Minnesota, experiences higher winds more frequently than the other sites because of its open, exposed site. In fact, the state with the greatest estimated wind-energy resource is North Dakota, with its open prairies and frequent strong, sustained winds. However, because of transmission distance and low competing energy prices, only a fraction of wind-power potential can be exploited economically.

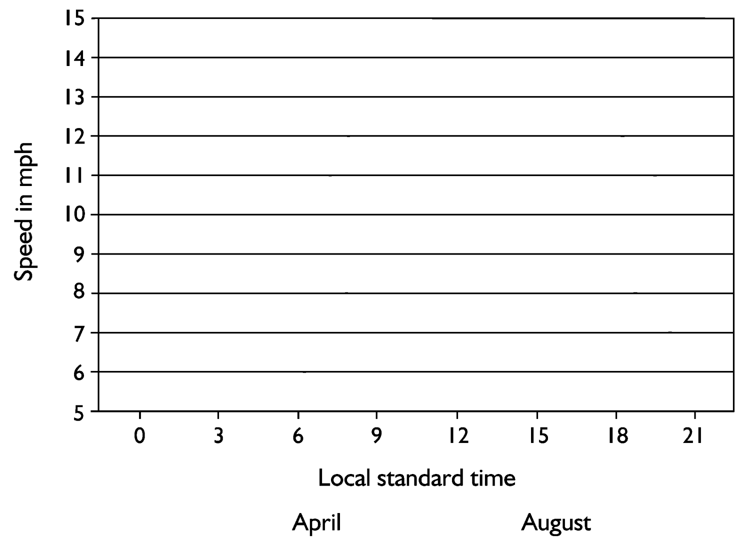
The distribution of wind speed over the day can also be an important factor in energy generation because power demands rise and fall with temperature and human activities. Figure 11 shows the variation of wind speed over the day for Madison in April and August, the months with the highest and lowest average wind speeds, respectively.

April and August wind speeds vary in a similar pattern. The lightest winds generally occur over the nighttime hours, when solar heating is not a factor. When the sun rises, the heat from the sun stirs up the air and helps to rapidly increase wind speeds. Wind speeds generally reach their peak in early to mid-afternoon, when the sun's heating is at its most intense. As afternoon changes to evening, wind speeds gradually diminish. Many sailors have learned by experience that winds often die down quickly after sunset, leaving them stranded in the middle of the lake.

Table 1. *Annual frequency of wind speed (miles per hour) from hourly observations by category, in percent. An asterisk indicates a probability of less than 0.1 percent. This table does not include wind gusts, which are of much shorter duration. The locations of the stations are shown in figure 13.*

Station	1–4 mph	5–7 mph	8–12 mph	13–18 mph	19–24 mph	25–31 mph	32–38 mph	39–46 mph	47–54 mph	55–63 mph	>63 mph
Madison	7.1	21.9	31.9	25.3	4.9	1.1	0.2	*	*	*	0
Milwaukee	5.5	17.8	34.2	30.6	7.5	1.9	0.3	*	*	*	0
Green Bay	6.6	25.6	33.0	24.2	5.4	0.9	0.1	*	*	*	0
Duluth	3.7	19.4	35.0	29.9	6.4	1.8	0.4	0.1	*	*	*
Minneapolis	6.7	21.1	33.6	28.0	5.9	1.2	0.1	*	*	0	*
Rochester	4.5	14.8	32.5	31.1	10.9	2.7	0.4	0.1	*	0	0
Waterloo	5.3	21.5	30.4	27.9	7.5	1.4	0.2	*	*	0	0
Moline	5.9	21.3	31.0	26.4	5.3	1.3	0.2	*	*	*	0
Rockford	6.9	23.4	31.8	26.9	4.7	0.9	0.1	*	*	0	0
Chicago	3.9	25.7	35.6	25.6	5.0	1.0	0.1	*	*	0	0

Figure 11. Madison wind speed by hour for April and August, the windiest and least windy month, respectively.



Because Wisconsin is not known for its strong, steady winds, the state is not often considered suitable for large-scale wind-energy projects. However, there are several areas of the state where wind speeds are high enough to economically install wind machines. The map in figure 12 shows the relative wind-energy potential for different regions in Wisconsin. The best wind-power sites have steady winds that are higher than 10 mph and come from a relatively constant direction.

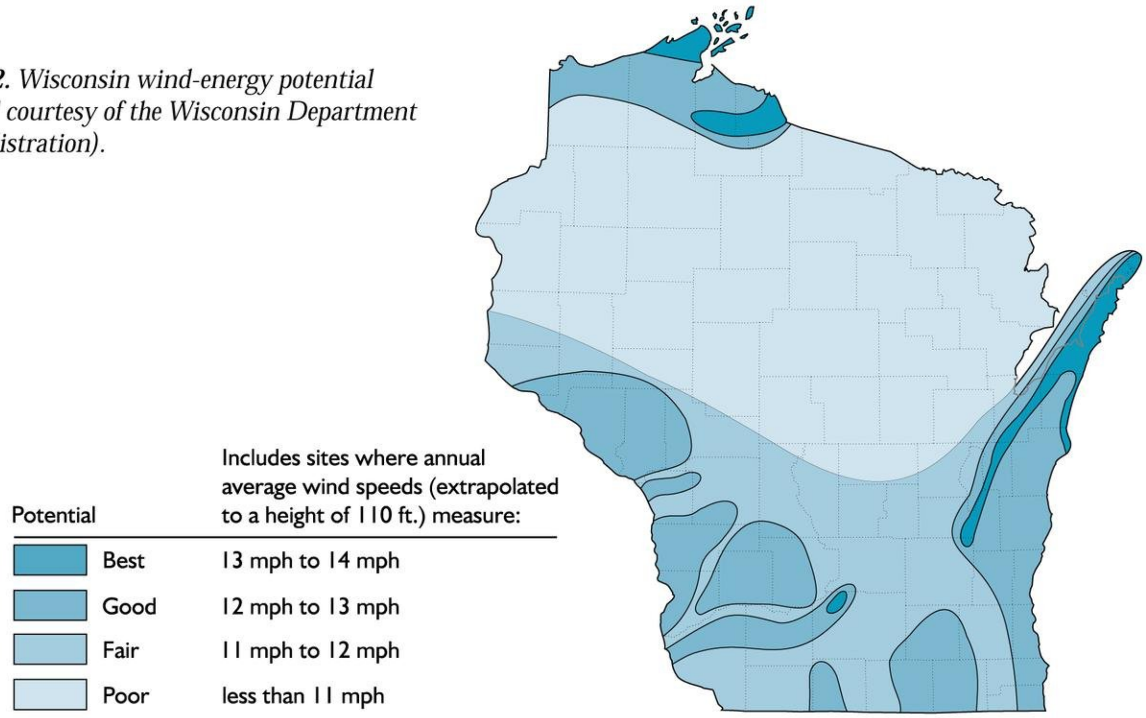
Many of the best sites in Wisconsin have winds that are affected by local topography, such as the Baraboo Hills, or lake-effect breezes. Because local topography can vary significantly over relatively small regions, each potential wind site should be evaluated separately to incorporate the effects of local wind variation. The local evaluation can also take into account other factors such as migratory bird flight paths, proximity to aviation landing and takeoff zones, and wildlife refuges. Some areas even within the "poor potential" category may be suitable for wind power because of their local characteristics. It is also important to keep in mind that as technologies continue to improve, many more sites may be able to use wind power effectively in the future.

WIND-CHARACTERISTIC DATA

Sources of data

In the back of this atlas, winds for a number of National Weather Service stations are shown for each month of the year. The major source of these data are the 1948–90 hourly data summaries in the International Station Meteorological Climate Summary, version 2.0. This CD-ROM was published in June 1992 by the National Climatic Data Center; it contains weather summaries for 5,000 meteorological stations around the world. Gust information for most stations was supplemented for 1991–93 from the National Climatic Data Center's *Climatological Data* publications for individual stations.

Figure 12. Wisconsin wind-energy potential (provided courtesy of the Wisconsin Department of Administration).



Data for a few supplemental stations (La Crosse, Eau Claire, and Sawyer/Gwinn in the Upper Peninsula of Michigan) were obtained from the Midwestern Climate Center in Champaign, Illinois, from the electronic bulletin board, MICIS. The tables of wind information for each month are not completely filled for these three stations. Locations of stations are shown in figure 13; station information is given in table 2.

Figure 13. Location of stations from which wind observations were taken.

Table 2. Station characteristics and length of record

Station	Latitude	Longitude	Elevation above sea level (in ft)	Anemometer height above ground (in ft)	Years of record—average winds	Years of record—gusts
Madison	43° 08'	89° 20'	858	33	1948–90	1971–93
Milwaukee	42° 57'	87° 54'	676	20	1948–90	1970–93
Green Bay	44° 29'	88° 08'	682	20/33	1948–90	1975–93
La Crosse	43° 52'	91° 15'	651	21	1948–93	
Eau Claire	44° 52'	91° 29'	887	unknown	1949–93	
Duluth	46° 50'	92° 11'	1,428	21	1948–90	1966–93
Minneapolis	44° 53'	93° 13'	834	33	1948–90	1977–93
Rochester	43° 55'	92° 30'	1,297	30	1948–90	1972–93
Waterloo	42° 33'	92° 24'	868	20	1949–90	1976–90
Moline	41° 27'	90° 30'	582	25	1948–90	1972–90
Rockford	42° 12'	89° 06'	724	33/20	1951–90	1971–93
Chicago	41° 59'	87° 54'	674	20?	1958–90	1962–93
Sawyer/Gwinn	46° 20'	87° 23'	1,220	unknown	1956–70	

Wind-rose interpretation

A wind rose is a graphical method of displaying information about the frequency of winds from different directions. The length of the bar in each direction shows the likelihood of wind from each point on the compass (remember, wind is shown in the direction *from which* it comes). The longer the bar, the more frequently the wind blows from that direction. Wind roses are drawn on a polar graph with north at the top, east to the right, south on the bottom, and west to the left. In figure 14, the most frequent wind is from the west–northwest 12.5 percent of the time. The least frequent wind is from the south–southeast at 2.0 percent. Winds speeds less than 3 mph are below the operating threshold of the anemometers and are counted as calm conditions.

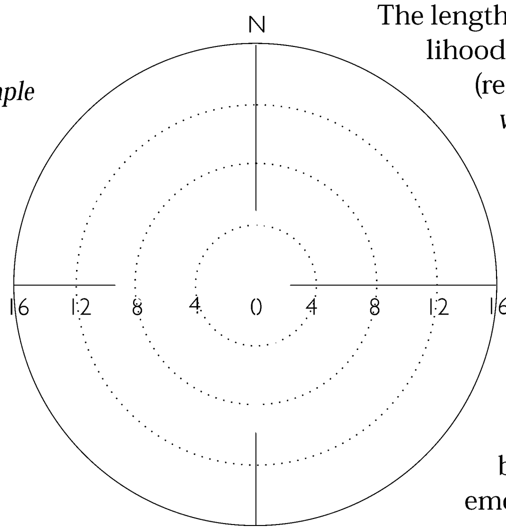


Figure 14. *An example of a wind rose.*

Directional frequency of occurrence data

The directional frequency of occurrence data from the ISMCS CD-ROM was reported for 16 directions; the data from MICIS were reported from 36 directions. To make these data comparable, the 36-point data were interpolated to a 16-point wind rose using weighted averages of wind frequency from each of the 36 directions. To check for errors, this technique was also performed on 36-point MICIS data for Madison and Minneapolis. Comparisons of the converted wind rose with the ISMCS 16-point wind rose showed good correspondence between the two.

Annual conditions. The annual wind roses for stations in and near Wisconsin show regional wind characteristics, which reflect average annual weather patterns in the Midwest, and the effects of local relief on these wind patterns (fig. 15). Stations in the north and west show frequent winds from the northwest and secondary peaks from the south. Southern stations show more evenly balanced annual wind roses, but the highest frequencies are from the south. This difference is due in large part to the regional weather patterns that affect the area. Western and northern stations are influenced by flow out of Canada from the northwest for much of the year; southern stations experience flow out of the south or southwest more frequently because they are nearer the main storm track.

Location also plays a role in determining average wind conditions at these sites. The station at La Crosse, for example, is located in a valley with northwest to southeast axes (table 3). This makes up-valley and down-valley winds more likely because of a lack of obstacles in those directions; this tendency can be seen in the northwest–southeast orientation of the wind rose. Note that Eau Claire does not reflect this distribution but instead reflects its west–southwest-oriented valley to some degree. Because Eau Claire's wind data appear quite different than the wind data from the other stations, they may indicate a problem with the representativeness of the location, and should be used with caution. In addition, the stations near Lake Michigan also show some preference for northeastern flow due to the presence of the cold lake waters in spring. This is most apparent in the maps for individual months.

Table 3. *Annual wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	9.8	S 12.4	7.6	61.9	9.3	83 W	JUN 1975
						83 N	JUL 1991
Milwaukee	11.4	WNW 10.9	2.2	63.0	6.7	81 NW	JUL 1984
Green Bay	10.0	SW 11.7	4.2	56.2	8.1	81 W	MAY 1989
La Crosse	10.0	S					
Eau Claire	10.1	WSW					
Duluth	11.3	NW 12.8	3.3	58.3	7.8	71 E	MAR 1985
						71 W	MAY 1981
Minneapolis	10.6	NW 11.0	3.4	58.2	6.7	71 W	AUG 1988
Rochester	12.1	S 13.2	3.0	70.3	7.8	90 SW	MAR 1982
Waterloo	10.7	NW 13.0	5.8	62.3	16.3	105 N	JULY 1980
Moline	10.0	WNW 10.2	8.5	67.5	8.3	81 N	APR 1987
Rockford	10.0	S 13.8	5.3	60.7	8.3	81 W	MAY 1988
Chicago	10.4	SSW 11.4	3.1	57.4	6.9	84 SW	MAR 1991
Sawyer/Gwinn	9.9	SSW					

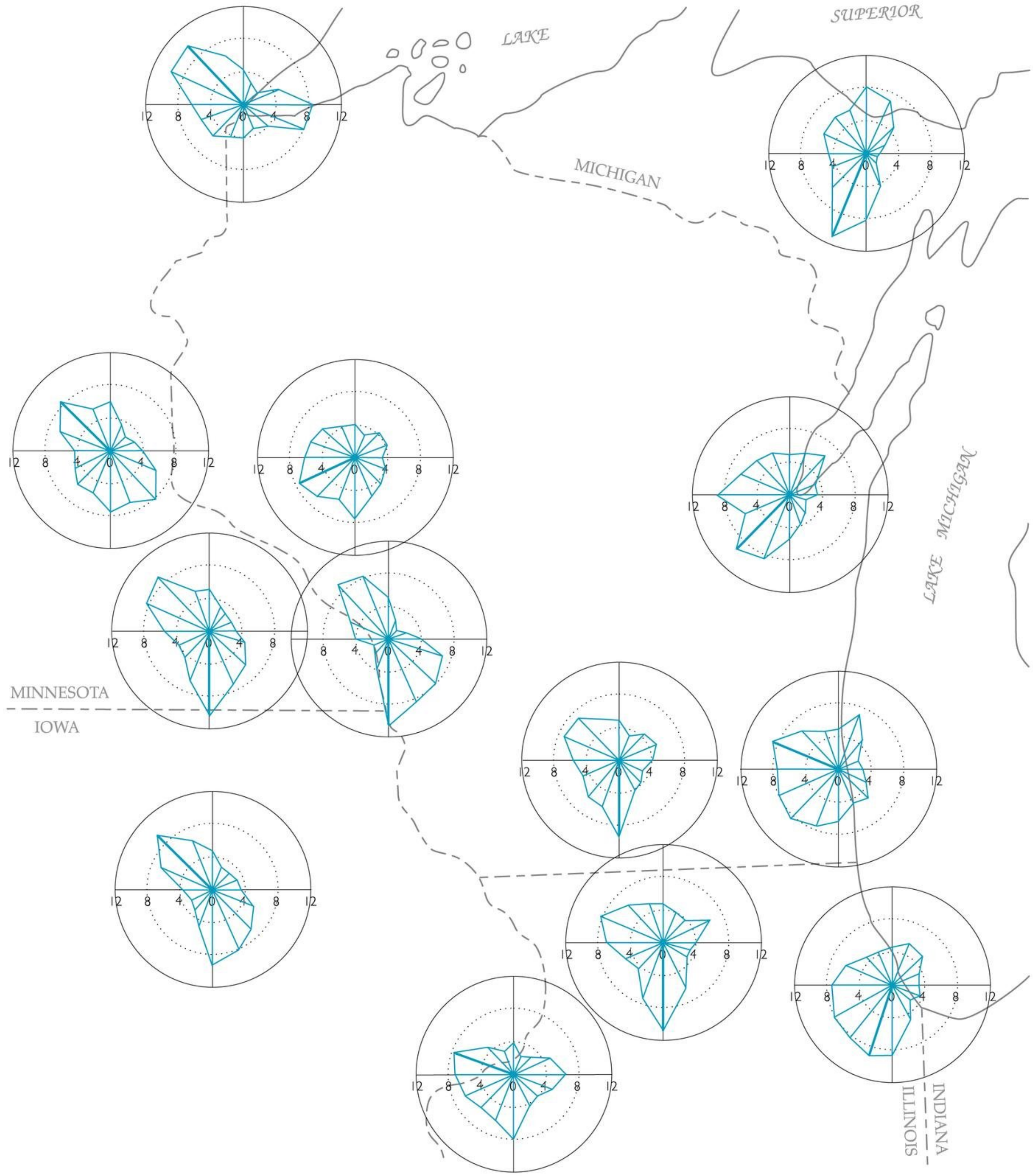
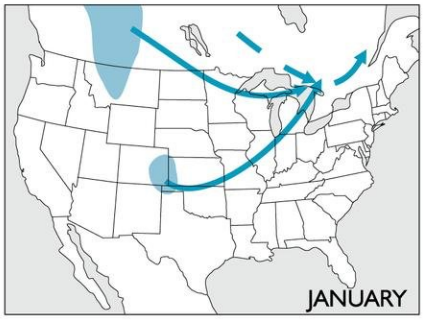


Figure 15. Annual wind roses for selected sites



January. During January, the major storm track in the United States is far to the south of Wisconsin, and most of the air entering the region is from the Canadian Arctic. Even the more westerly flow at the southeastern stations mainly represents arctic air that flowed south through the Great Plains and is returning northward. The westerly air flow at these sites also includes some moderate Pacific air that entered the region from the Pacific Northwest during periods when the wind was flowing zonally from west to east.

Wind speeds in January are fairly high, reflecting the strong push of Arctic air from the north during this month (table 4). The highest winds are often associated with the passage of strong storms and strong jet streams aloft, and are often accompanied by blowing snow and dangerously low wind chills. The percentage of time that the winds are calm is fairly low, especially compared to summer months. The January wind roses (fig. 16) look similar to those of February (fig. 17). The frequency of winds from the northwest decreases at all stations except Sawyer/Gwinn. The incidence of winds from the north and east increases at most stations, but is particularly noticeable for stations near the Great Lakes.

Table 4. *January wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	10.5	WNW 11.5	6.0	44.0	6.7	58 NW	1978
Milwaukee	12.5	WNW 12.8	1.3	47.0	8.7	66 SW	1975
Green Bay	11.0	W 11.5	3.1	43.2	9.9	69 SW	1975
La Crosse	9.9	NW					
Eau Claire	9.9	WSW					
Duluth	11.8	NW 13.6	3.0	42.3	9.1	58 NW	1972
Minneapolis	10.5	NW 13.5	2.7	44.3	8.4	67 NW	1986
Rochester	13.3	NW 15.3	2.3	53.5	9.2	69 NW	1986
Waterloo	11.6	NW 14.5	4.3	46.9	6.0	54 NW	1985
Moline	11.0	WNW 14.6	5.4	49.2	6.8	59 W 59 NW	1990 1980
Rockford	10.8	WNW 13.0	3.5	45.3	7.4	56*	1972
Chicago	11.6	W 11.8	1.6	45.1	7.2	58 W	1989
Sawyer/Gwinn	10.5	NW					

* not reported

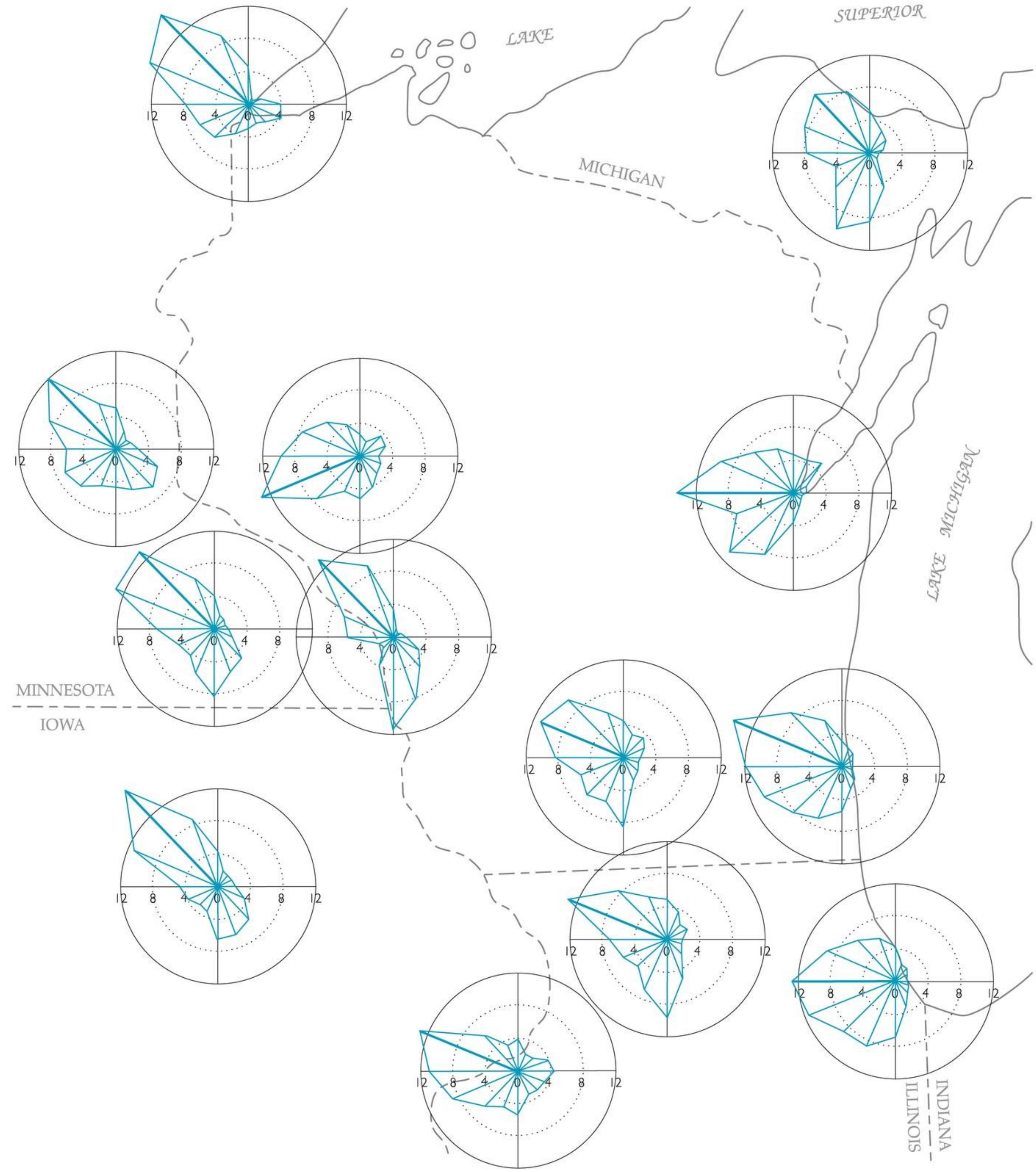
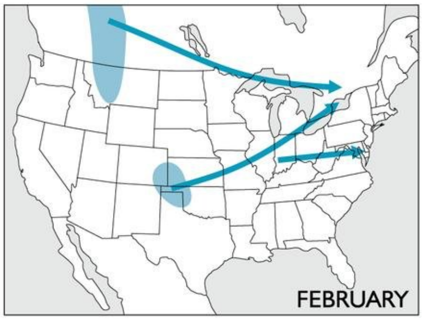


Figure 16. *January wind roses for selected sites.*



February. During February, the storm track starts to head back toward the north, albeit slowly. The increased presence of north and east winds (fig. 17) may reflect the more frequent proximity of storms to southern Wisconsin; these east winds are associated with the circulation of air on the north side of the low-pressure systems migrating along the storm track.

Wind speeds in February are slightly less than those in January at all stations except Sawyer/Gwinn, where winds from the north in particular have increased from the last month (table 5). The percentage calm is slightly higher at all stations except Chicago than in January. The unusually high percentage of calm conditions in Madison is due to the station's location in a low-lying area and can be seen in statistics for all months.

Table 5. *February wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	10.4	WNW 12.0	6.9	40.6	7.6	62 NW	1987
Milwaukee	12.3	WNW 12.4	1.8	43.7	7.4	67 W	1971
Bay	10.7	W 10.6	3.5	40.1	8.1	55 NE	1975
La Crosse	9.8	NW					
Eau Claire	9.8	WSW					
Duluth	11.5	NW 12.9	3.3	40.6	7.4	55 NW	1967
Minneapolis	10.4	NW 13.3	3.3	40.9	5.5	55 NW	1987
Rochester	12.8	NW 14.8	2.8	46.8	5.3	56 WNW	1975
Waterloo	11.5	NW 14.0	4.7	42.4	7.1	52 N	1981
Moline	10.9	WNW 12.8	5.7	41.4	4.8	54*	1990
Rockford	10.8	WNW 12.8	4.3	41.5	5.9	54*	1987
Chicago	11.5	W 10.7	1.6	42.9	6.6	54 WSW	1967
						54 SW	1971
						54 N	1990
Sawyer/Gwinn	10.7	N					

* not reported

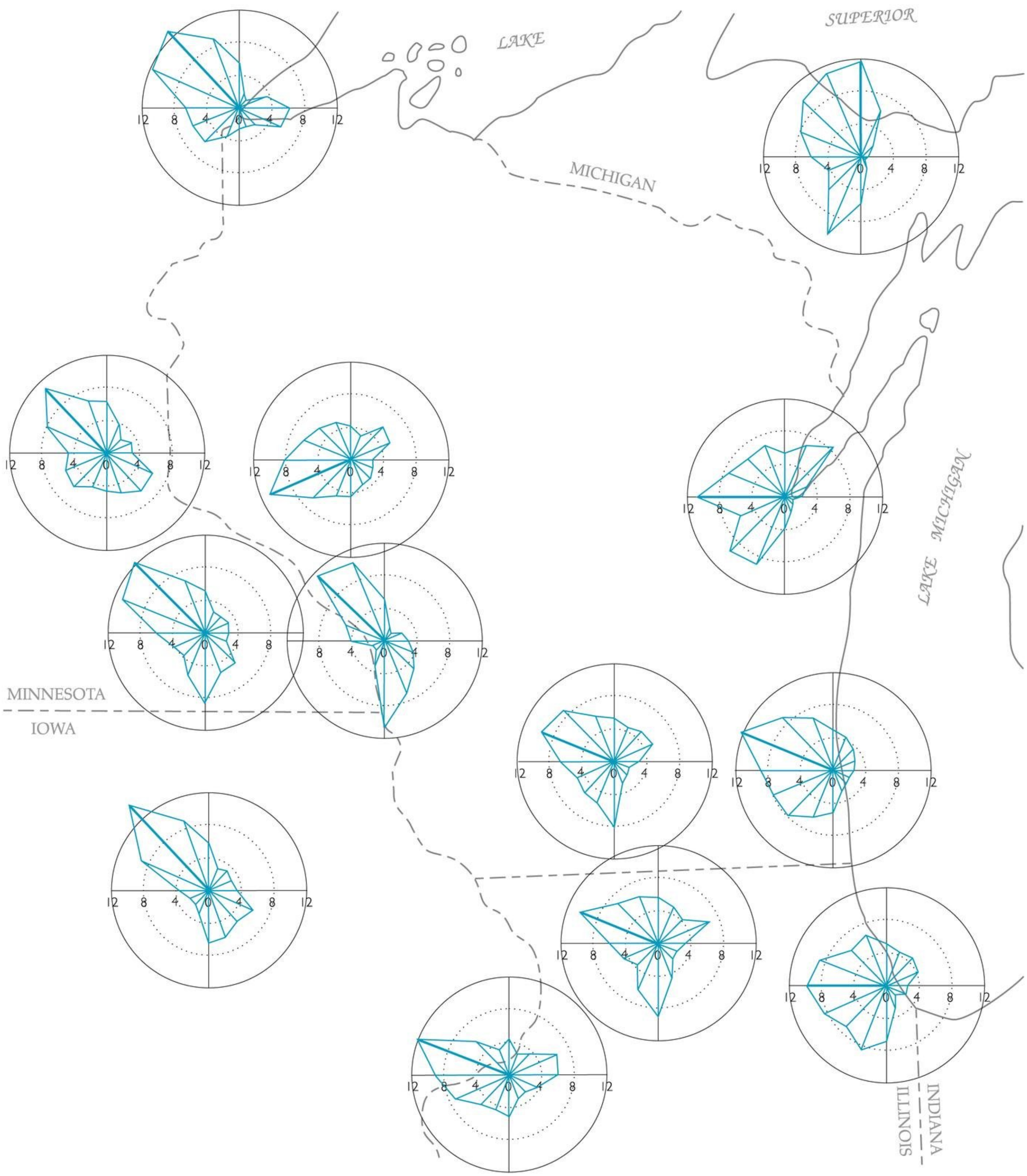
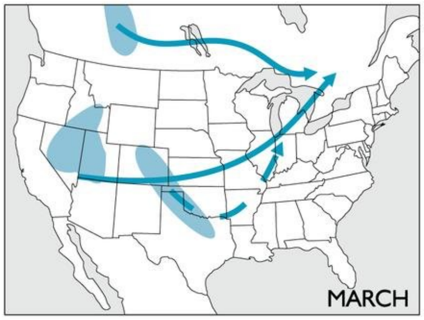


Figure 17. February wind roses for selected sites.



March. According to folklore, March "comes in like a lion and goes out like a lamb." It is also known as the month for kite flying. Wind speeds increase at every site except Sawyer/Gwinn, reflecting the movement of the storm track and associated jet stream northward toward Wisconsin (table 6). The percentage of calm conditions also decreases at every station except Chicago. Storms also tend to be more intense in spring and fall due to stronger temperature gradients across the United States during those seasons.

In March, the approach of the storm track toward southern Wisconsin increases the likelihood of winds with an easterly component (fig. 18). In Green Bay, the northeastern wind becomes the prevailing wind, representing the effects of the cold bay and the local orientation of the Fox River valley. Similar effects are apparent in the wind rose for Duluth. In the south and east, wind roses show the frequency of winds from northeast, northwest, and south to be more equal than in previous months; in the west prevailing winds still tend to be from the northwest. The most likely wind direction from Eau Claire in March is east–northeast.

Table 6. *March wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	11.3	NW 13.0	6.1	48.0	8.4	67 S	1990
Milwaukee	12.8	WNW 12.7	2.0	48.4	5.8	77 SW	1991
Green Bay	10.9	NE 12.3	3.0	44.3	7.0	58 W	1982
La Crosse	10.7	NW					
Eau Claire	10.9	ENE					
Duluth	12.1	E 14.5	3.3	45.5	9.1	71 E	1985
Minneapolis	11.4	NW 13.2	2.4	46.9	6.0	60 W	1988
Rochester	13.3	NW 15.1	2.7	56.1	12.0	90 SW	1982
Waterloo	12.5	NW 14.6	3.4	46.4	5.5	59*	1982
Moline	12.2	WNW 14.7	4.8	49.1	8.2	63 SW	1982
Rockford	11.7	WNW 12.5	3.1	47.3	4.7	54 SW	1990
Chicago	12.0	W 11.0	1.7	47.4	6.9	84 SW	1991
Sawyer/Gwinn	10.2	N					

* not reported

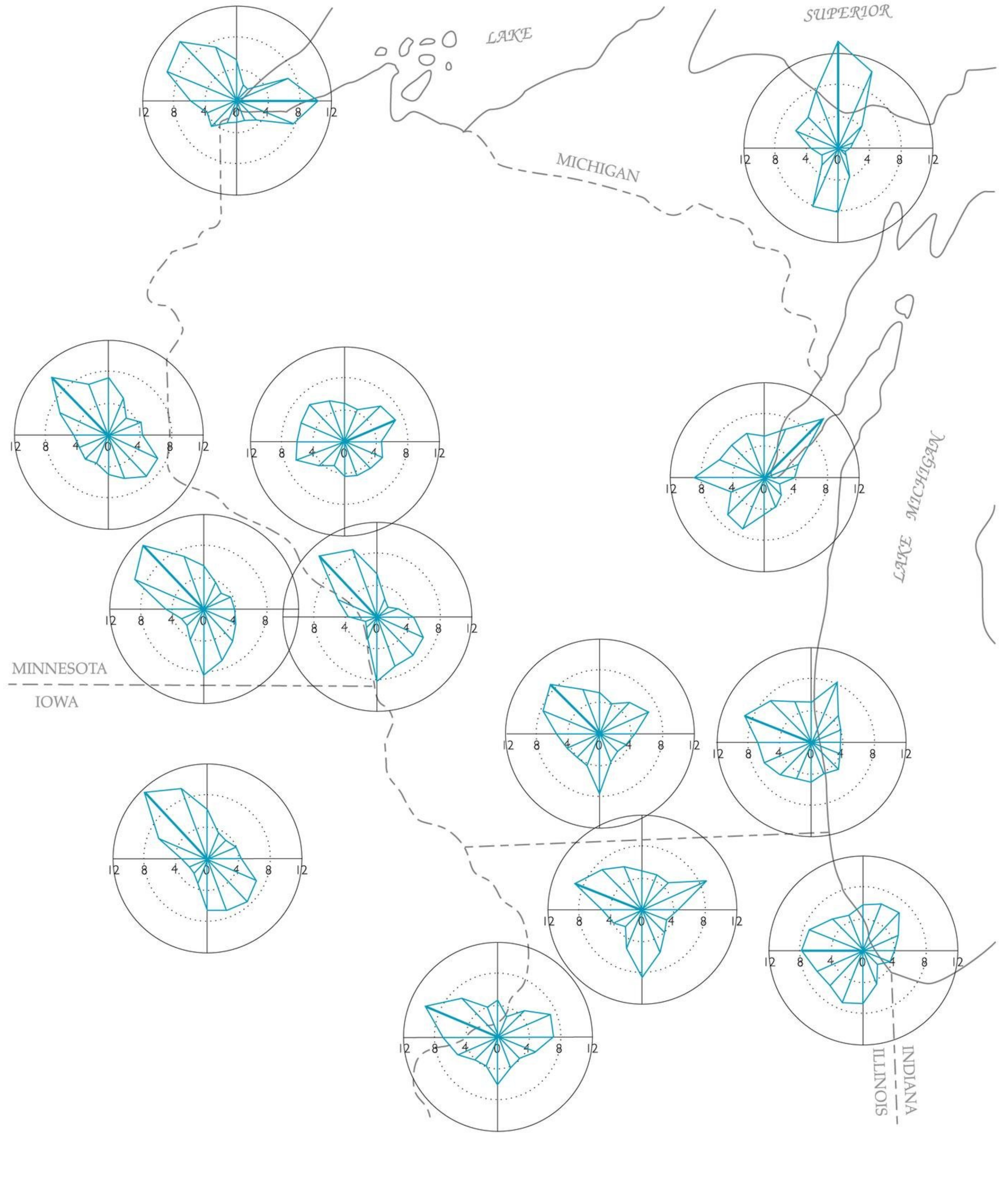
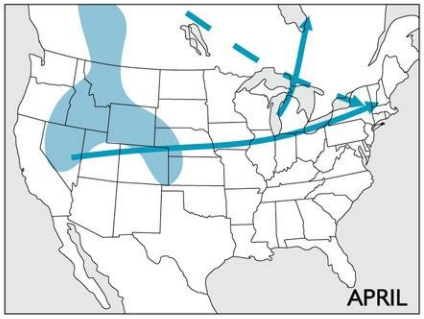


Figure 18. *March wind roses for selected sites.*



April. In April, the storm track is often located in central to northern Illinois. Frequent passage of low-pressure areas along this storm track provides numerous occurrences of easterly flow in locations across Wisconsin, especially in the south. Frequency of northeasterly winds near Lake Michigan also increases due to the sharp temperature contrasts between the cold lake and the warming land to the west. The likelihood of winds from the south is similar to that of March; the frequency of northwestern winds decreases at northern and western stations.

Wind speeds increase from the March values at all locations except Madison, Moline, and Chicago (table 7). The magnitude of the increase varies with each station. The percentage of calm conditions also rises at all stations except Green Bay and Duluth, which are increasingly affected by the spring lake breezes.

The April wind rose for Moline illustrates one problem wind data may have—the propensity of human observers reading the wind instruments to bias readings toward the cardinal points of north, south, east, and west (fig. 19). The slightly higher frequency of winds from the north, compared to the frequencies of winds from the north–northeast and north–northwest, is probably an artifact of the observation process rather than a true representation of local winds. This effect can be seen in other monthly wind roses at Moline and at other locations.

Table 7. *April wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	11.4	S 11.4	6.4	47.7	7.0	61 SW	1981
Milwaukee	12.7	NNE 13.9	2.1	49.8	7.6	67 W	1979
Green Bay	11.3	NE 12.1	2.5	43.6	8.6	68 NW	1982
La Crosse	12.1	S					
Eau Claire	12.1	NE					
Duluth	12.7	E 14.4	3.2	46.3	6.2	60 E	1986
Minneapolis	12.3	NW 14.3	2.9	48.6	7.2	61 SW	1984
Rochester	13.7	NW 15.3	2.6	54.7	10.2	85 S	1984
Waterloo	12.8	NW 15.4	3.9	50.0	8.9	76*	1978
Moline	12.1	WNW 14.8	5.7	54.7	10.6	81 SW	1981
Rockford	11.8	ENE 12.9	3.5	49.6	7.7	64*	1979
Chicago	12.0	NNE 13.1	2.1	49.9	9.2	69 SW	1965
						69 S	1984
Sawyer/Gwinn	10.8	NNE					

* not reported

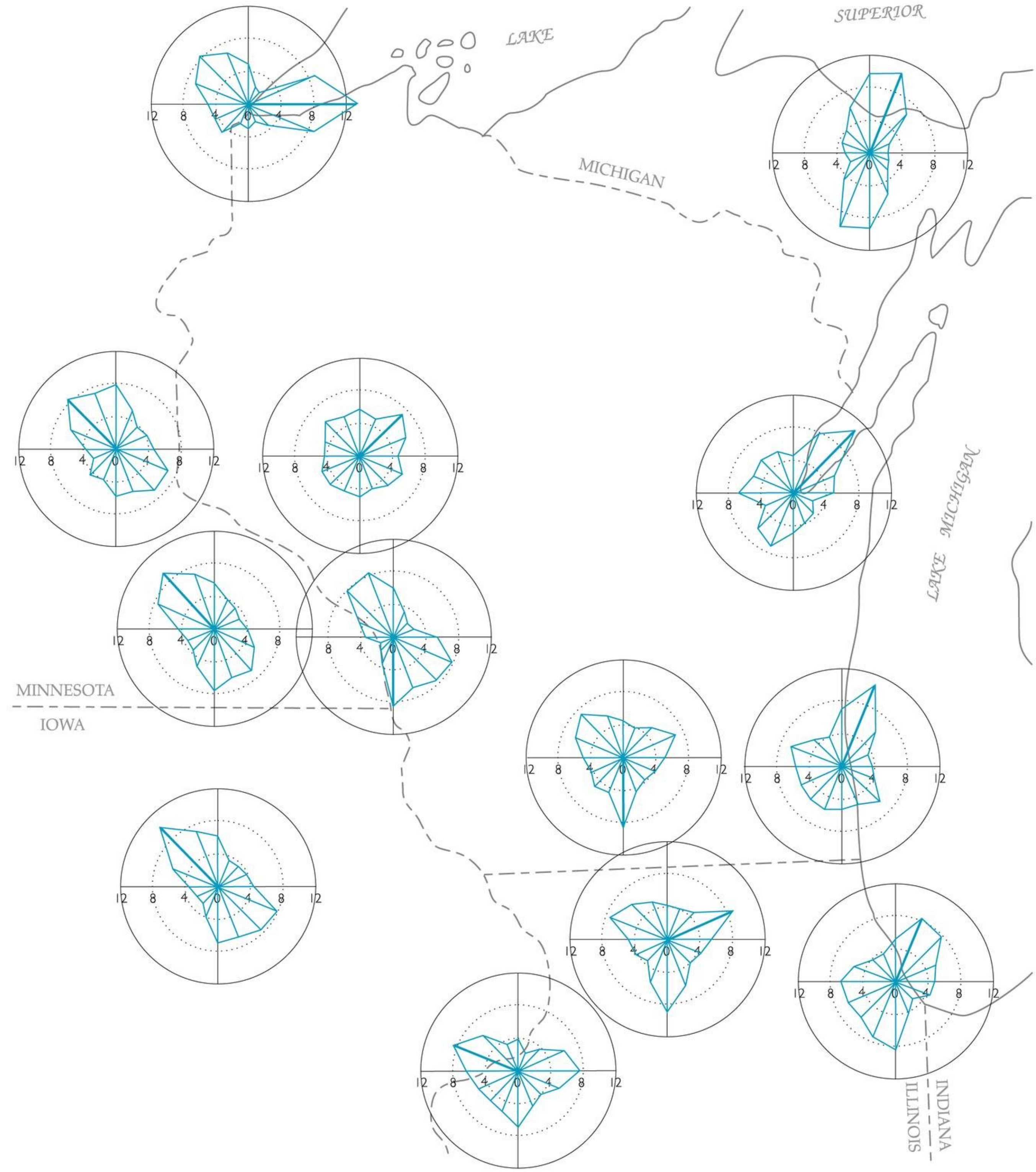
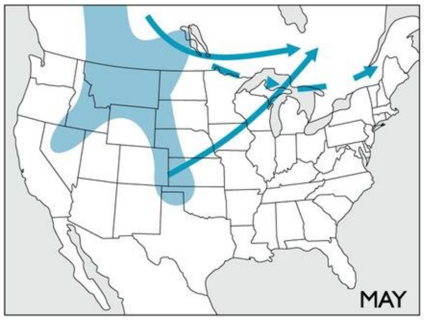


Figure 19. April wind roses for selected sites.



May. In May, the northeasterly component of winds at stations near Lake Michigan reaches its maximum extent. In Milwaukee, the prevailing north–northeast wind that is observed (instead of the easterly wind that would be expected) is a reflection of the local shoreline configuration. Significant heating of the land by sunlight and a cold lake provide a strong contrast that drives the lake breeze at eastern locations. This is enhanced by the higher sun angle and the absence of snow cover on the ground.

Winds from the south and southeast become the most frequent at western stations as the storm track brings east winds north of the low-pressure areas closer to these sites (fig. 20). At many sites, winds are nearly evenly distributed from all directions, indicating that the storm track is nearby. Eau Claire, Moline, and Rockford all show prevailing winds equally divided between two directions.

Wind speeds in May decrease from their April values, making April the windiest spring month (table 8). The percentage of calm conditions continues to increase at all stations except Duluth, and is especially noticeable at Moline and Rockford.

Table 8. *May wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	10.1	S 10.4	7.0	47.3	8.2	64 SW	1975
Milwaukee	11.5	NNE 13.2	2.4	47.8	9.1	74 SW	1974
Green Bay	10.2	NE 11.6	4.4	45.5	10.9	81 W	1989
La Crosse	10.7	S					
Eau Claire	11.3	NE and S					
Duluth	11.8	E 13.0	3.0	44.5	7.6	71 W	1981
Minneapolis	11.3	SE 11.2	3.7	47.8	4.3	67*	1985
Rochester	12.3	S 13.9	3.3	57.0	8.3	76 S	1972
Waterloo	11.0	S 12.2	5.8	50.0	9.1	68 N	1980
Moline	10.4	E 9.7 S 12.1	8.5	51.9	6.3	66 SW	1977
Rockford	10.5	ENE 10.9 S 10.4	5.0	49.6	10.0	81 W	1988
Chicago	10.6	NNE 11.5	2.9	45.0	6.0	58 N	1983
Sawyer/Gwinn	10.4	NNE					

* not reported

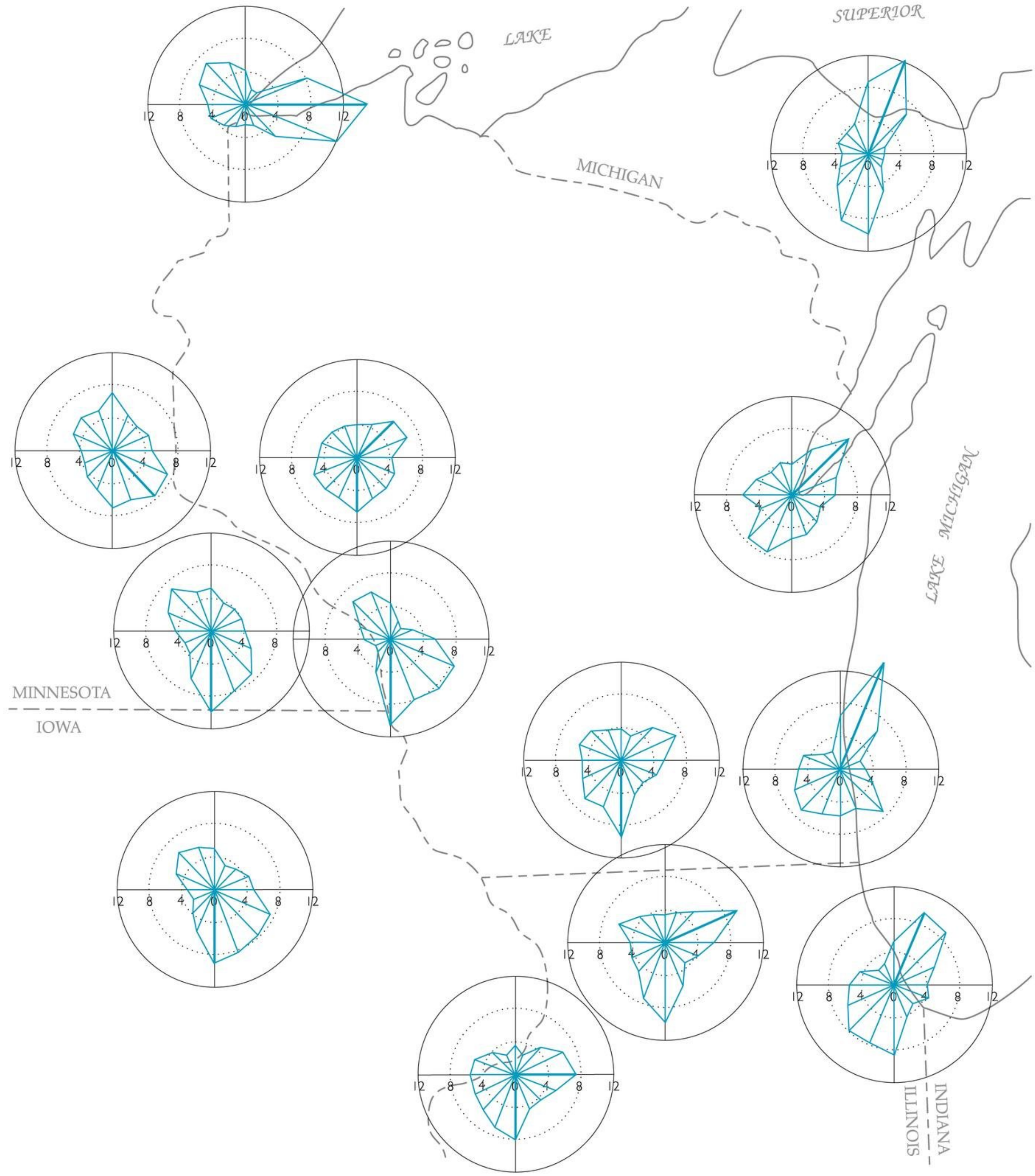
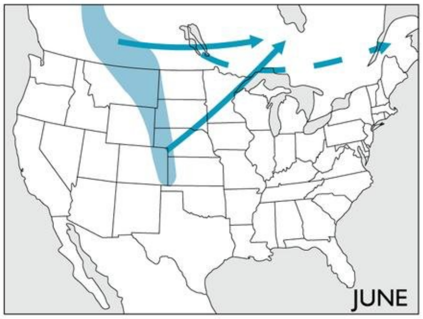


Figure 20. *May wind roses for selected sites.*



June. In June, air flow from the south dominates at all stations except Duluth and Milwaukee, where lake breezes still drive local winds (fig. 21). Sawyer/Gwinn, in northern Michigan, also exhibits a significant percentage of northeasterly winds. Southern Wisconsin experiences a peak in precipitation in June as the storm track moves through the state toward the north. Low-pressure areas draw warm, moist air ahead of them, providing fuel for convective showers and thunderstorms.

Wind speeds in June are from 0.5 to 1 mph lower than those measured in the May readings at all locations except Rockford (table 9). The percentage of calm conditions also increases significantly at many stations, reflecting the expanded presence of summertime high-pressure areas, which typically have light winds, warm temperatures, and sunny skies.

Record wind gusts in the spring and summer months are generally higher than in the winter, and are a reflection of the higher probability of severe thunderstorms during these months. With these dangerous thunderstorms comes the possibility of hail, strong wind gusts, and even tornadoes. Unfortunately, the highest winds often occur far from official wind gauges, so the actual gust record for a particular location does not reflect a most likely peak gust in any statistical sense. In Wisconsin, May and June are considered the peak months for severe weather, although severe weather can occur in any month. Tornadoes have been observed in Wisconsin in every month except February.

Table 9. *June wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	9.2	S 9.7	8.4	50.7	11.7	83 W	1975
Milwaukee	10.4	NNE 11.3	2.2	50.1	9.4	76 W	1971
Green Bay	9.2	SSW 10.4 SW 10.8	4.4	42.9	10.2	70 SW	1976
La Crosse	9.5	S					
Eau Claire	10.2	S					
Duluth	10.7	ESE 10.4	3.6	43.8	7.5	69 W	1986
Minneapolis	10.5	SE 10.5	3.5	50.1	7.5	66 NE	1974
Rochester	11.6	S 13.3	3.2	57.6	10.7	82 NE	1974
Waterloo	9.9	S 11.7	5.7	48.6	12.4	86 NW	1976
Moline	9.2	S 11.2	10.3	51.1	11.8	79 NW	1976
Rockford	10.6	S 8.7	5.8	46.3	8.5	67*	1974
Chicago	9.2	SSW 10.4	4.3	43.2	7.8	63 N 63 S	1977 1990
Sawyer/Gwinn	9.2	SSW					

* not reported

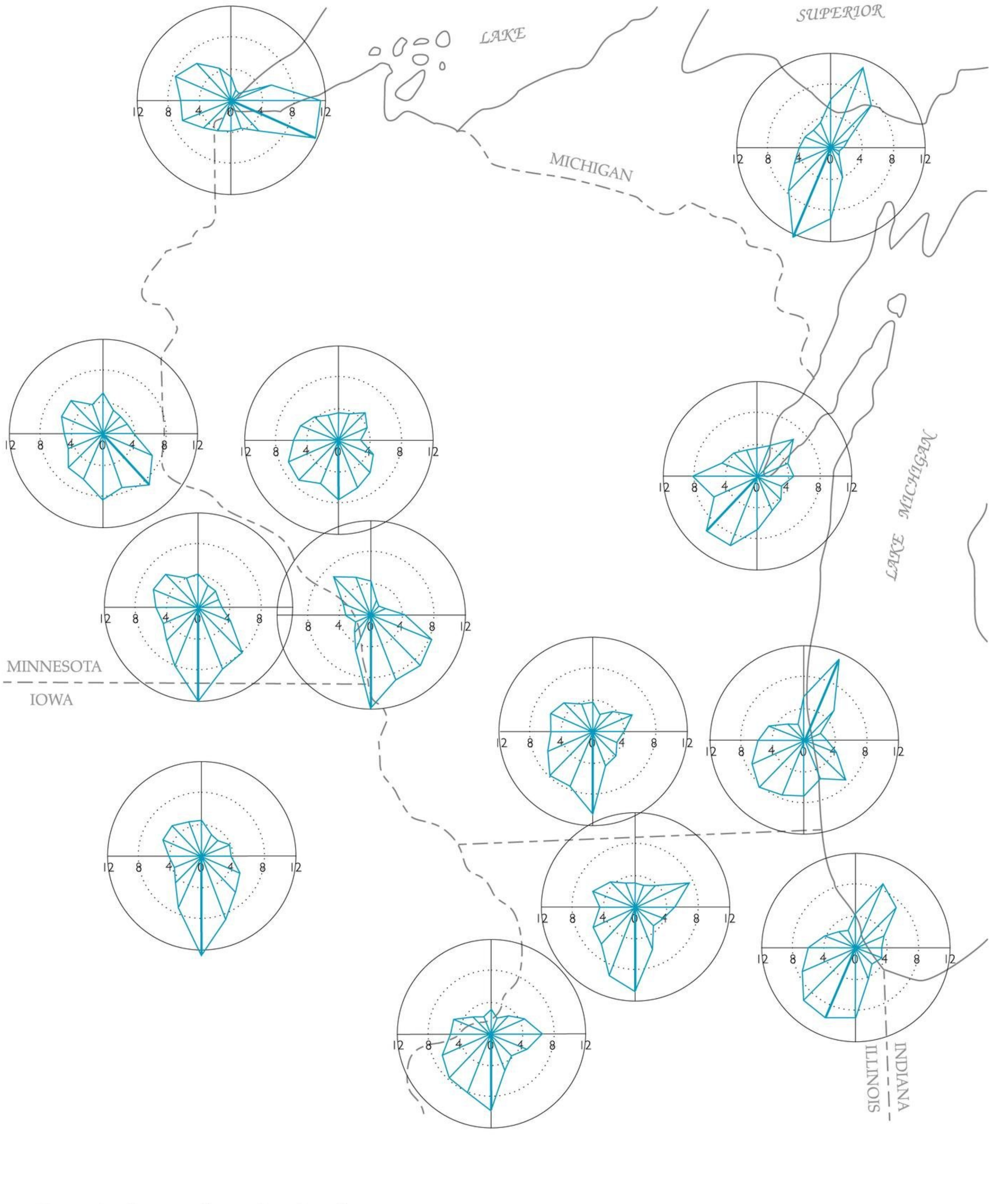
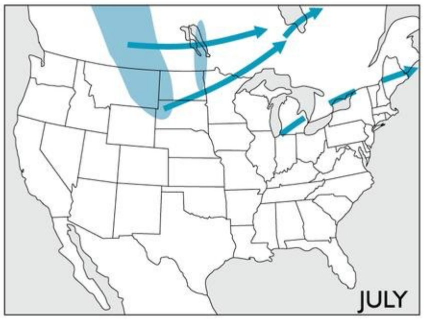


Figure 21. *June wind roses for selected sites.*



July. As the lakes continue to warm, the percentage of winds from the northeast continues to decline (fig. 22). Winds from the south to southwest dominate at all stations except Duluth. In July, the storm track is located at its northernmost position; this is reflected in the maximum of precipitation received in northern Wisconsin during this month.

Wind speeds in July are significantly lower than in June, revealing the reduced pressure gradients found across the continent in midsummer and the absence of active weather systems (table 10). High pressure and light winds tend to dominate the summer circulation, although individual storms or years can have unusually strong winds. The percentage of calm conditions continues to grow and reaches a peak in August across the region. The exceptionally high percentage of calm conditions at Moline is probably a reflection of the local conditions at the station because other stations farther south and west do not exhibit the same characteristics.

The record gust of 105 mph that occurred in Waterloo was associated with a severe downburst that hit the Waterloo airport from 12:42 to 12:54 AM on July 9, 1980. It blew the roof off the control tower and damaged approximately 70 airplanes and nine Air National Guard helicopters and damaged windows in several cars in the airport parking lot. In many cases, the highest winds strike far from the airport where no wind instruments can detect them.

Table 10. *July wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	8.1	S 9.2	9.9	45.7	9.0	83 N	1991
Milwaukee	9.7	SW 10.8	3.2	49.2	12.1	81 NW	1984
Green Bay	8.3	SW 9.5	6.8	44.2	9.4	60 SW	1980
La Crosse	8.5	S					
Eau Claire	9.0	S					
Duluth	9.7	WNW 10.9	4.5	41.4	6.9	61 NW	1967
Minneapolis	9.5	S 10.8	4.2	46.0	8.9	63 N	1983
Rochester	10.1	S 11.5	4.1	54.1	11.0	74 SW	1983
Waterloo	8.4	S 10.0	8.8	48.9	18.3	105 N	1980
Moline	7.7	S 9.7	12.6	46.9	10.8	66 NW	1980
Rockford	8.1	S 7.9	8.1	47.0	10.8	70*	1984
Chicago	8.2	SW 9.1	5.7	42.0	10.4	76 N	1980
Sawyer/Gwinn	8.2	SSW					

* not reported

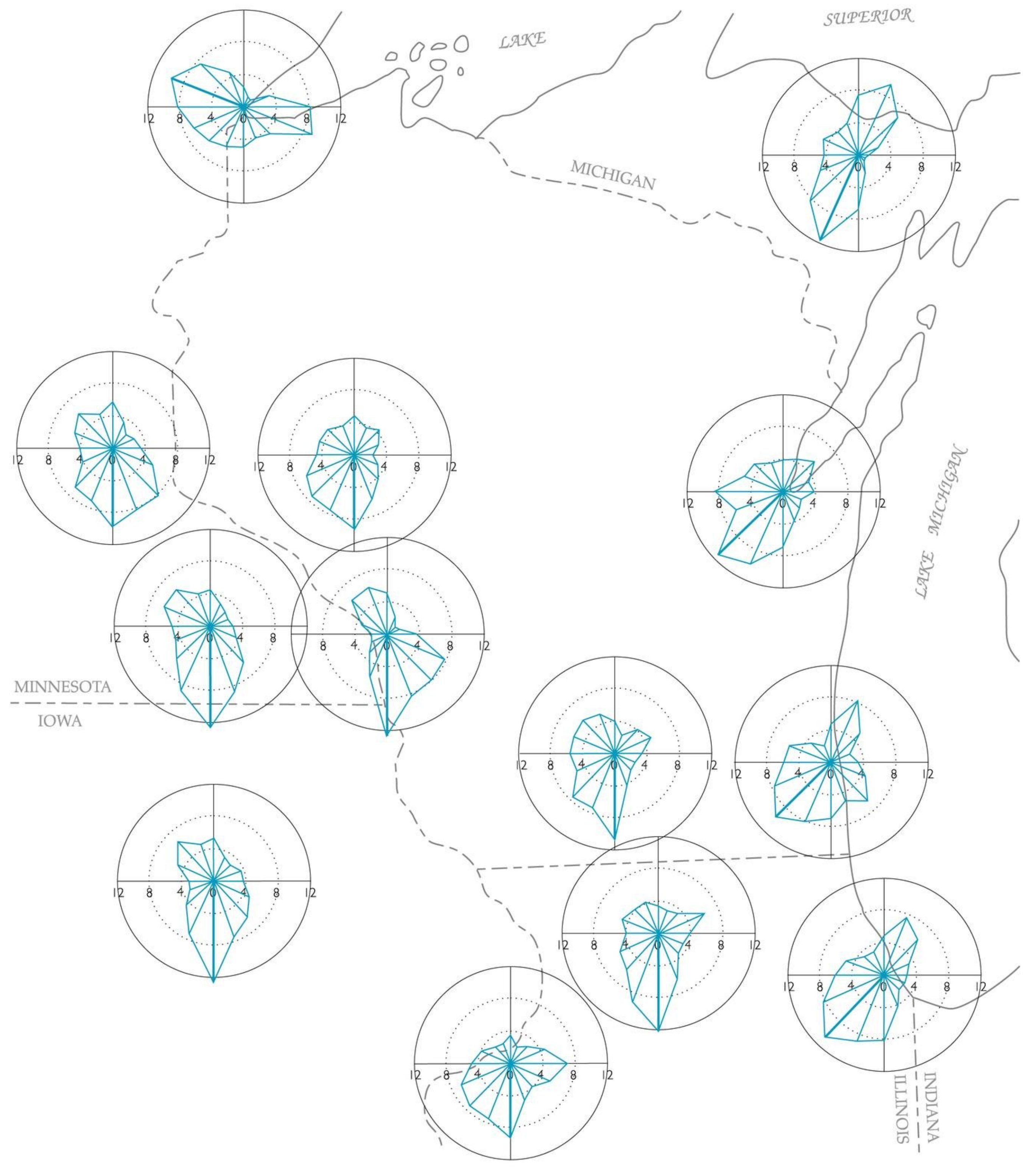


Figure 22. *July wind roses for selected sites.*

August. In August, the storm track begins to move back toward the south again. Precipitation in southern Wisconsin hits its second peak as the storm track sags south. However, percentages of southerly winds continue to remain strong, and even increase at some locations like La Crosse. Slightly higher proportions of easterly winds occur at western stations as east winds north of migrating lows become more frequent (fig. 23). By contrast, they decline at eastern lake stations due to the reduced temperature contrast between Lake Michigan and the warm land.

Wind speeds at all stations continue the downward trend started in May (table 11). The percentage of calm conditions reaches its maximum value at most southern locations but begins to decrease in Duluth and Minneapolis. Frequent passage of high-pressure centers through the upper Midwest contributes to the light winds and frequent calm conditions.

In southern Wisconsin, the last five days of August are the five-day period most likely to be dry during the year, making this time perfect for haying and outdoor activity. The stagnant conditions also help set up favorable conditions for occasional floods in northern and central Wisconsin, as warm and humid southerly flow moves up and over stationary fronts located along the storm track.

Table 11. *August wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	7.8	S 9.1	11.1	46.7	8.7	64 N	1989
Milwaukee	9.4	SW 10.4	3.2	45.2	8.7	64 NW	1989
Green Bay	7.9	SW 9.4	6.9	39.3	6.6	53 W	1985
La Crosse	8.3	S					
Eau Claire	8.7	S					
Duluth	9.5	ESE 9.5	4.3	39.8	7.1	56 SW	1975
Minneapolis	9.2	S 10.5	4.0	47.0	10.1	71 W	1988
Rochester	9.9	S 11.3	4.4	54.2	9.5	78 S	1980
Waterloo	8.4	S 10.4	9.0	41.5	6.4	51 W	1989
Moline	7.4	S 9.5	13.6	45.3	12.4	81 N	1987
Rockford	7.8	S 7.6	8.3	44.3	10.6	67*	1982
Chicago	8.1	SSW 9.2	5.5	41.3	9.3	64 W	1987
		SW 9.0					
Sawyer/Gwinn	8.2	SSW					

* not reported

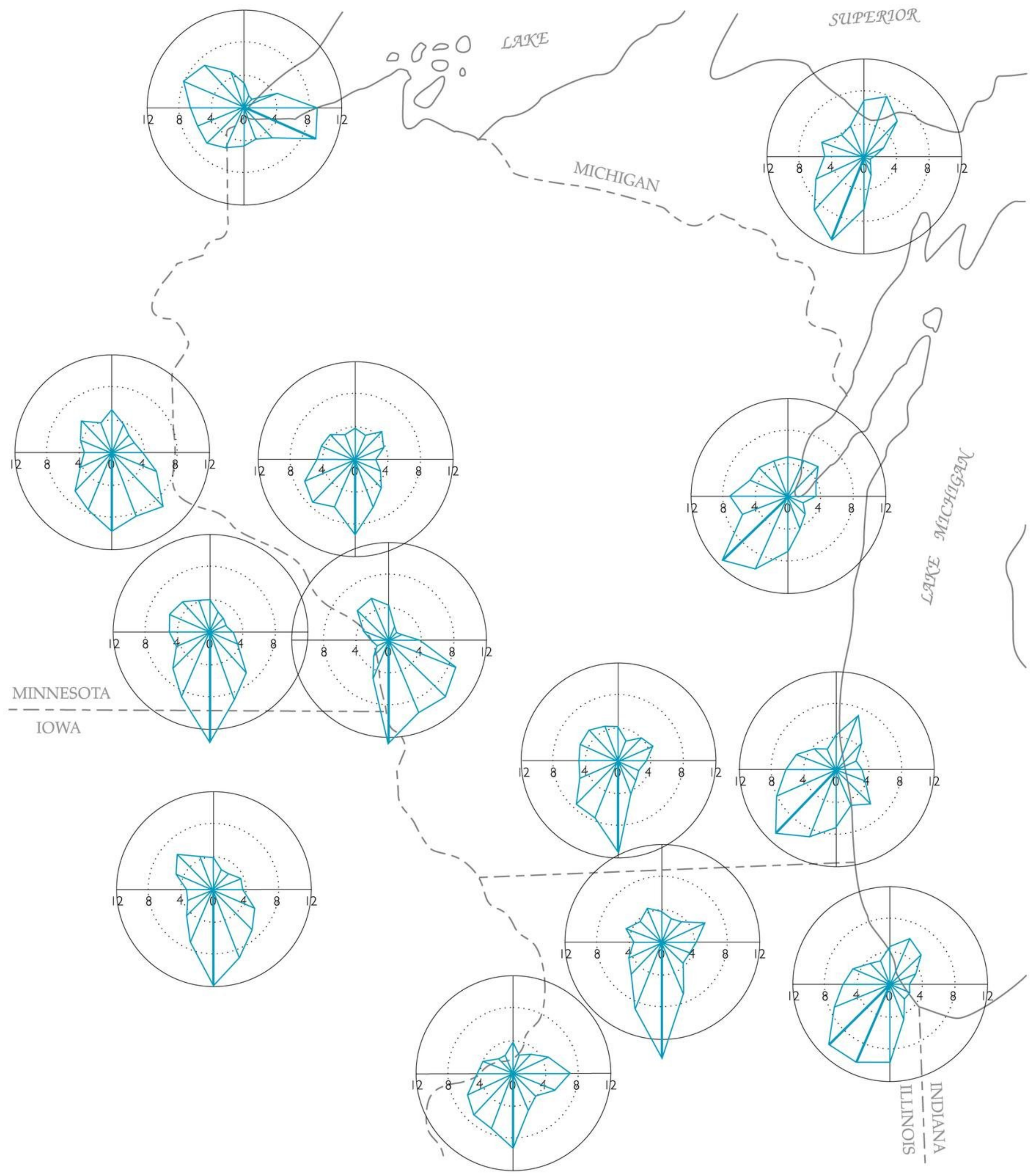
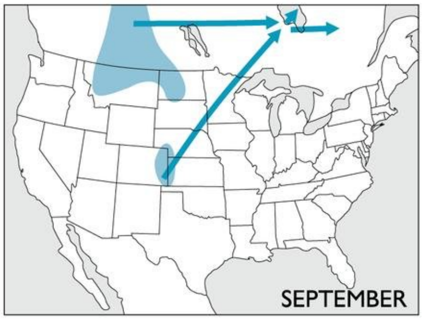


Figure 23. August wind roses for selected sites.



September. Southerly winds still predominate across the region in September, but the frequency of northwestern winds becomes higher at most sites and is especially noticeable in the west (fig. 24). At Duluth, the direction of the prevailing wind switches to west–northwest. In addition, because of daytime heating of the land surfaces, lake breezes from the northeast measured at stations near Lake Michigan can still occur with some frequency, even though average temperatures of the lake and land are nearly equal. In fact, the slowly cooling lake water helps delay the onset of fall near the shore because it holds back the influence of cold Arctic air, which is cooling other parts of the state.

Wind speeds in September increase from 0.5 to 1 mph from their August values at all stations in the region (table 12). The frequency of calm conditions decreases at all stations except for Moline, which continues to exhibit uncharacteristically high values.

In September, the onset of early fall conditions signals the return of an increased number of traveling low-pressure systems through Wisconsin. Warm southern air and moderate Pacific air blend in the circulation around the lows, but genuinely cold air seldom reaches as far south as Wisconsin. Calm conditions associated with cool high pressure following the passage of a low-pressure system in late September usually signal the end of the growing season by allowing the formation of frost on the ground beneath the quiet, cloudless atmosphere.

Table 12. *September wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	8.6	S 9.8	9.9	40.1	9.4	64 NW	1985
Milwaukee	10.4	SSW 11.0	2.8	44.6	8.5	62 NW	1980
Green Bay	9.0	SSW 10.5	5.2	38.5	4.6	48 SW	1976
La Crosse	9.2	S					
Eau Claire	9.4	S					
Duluth	10.6	WNW 11.5	3.4	40.2	7.2	60 SW	1991
Minneapolis	9.8	S 11.2	4.0	42.2	6.2	54 SW	1980
Rochester	11.0	S 12.7	3.6	49.5	6.7	64 S	1992
Waterloo	9.1	S 10.8	8.5	42.7	6.0	53 N	1978
Moline	8.2	S 10.6	13.8	42.3	8.6	59 W	1978
Rockford	8.5	S 8.4	7.7	39.3	6.9	58*	1988
Chicago	8.9	S 9.1	4.6	39.1	7.0	58 N	1989
Sawyer/Gwinn	8.5	SSW					

* not reported

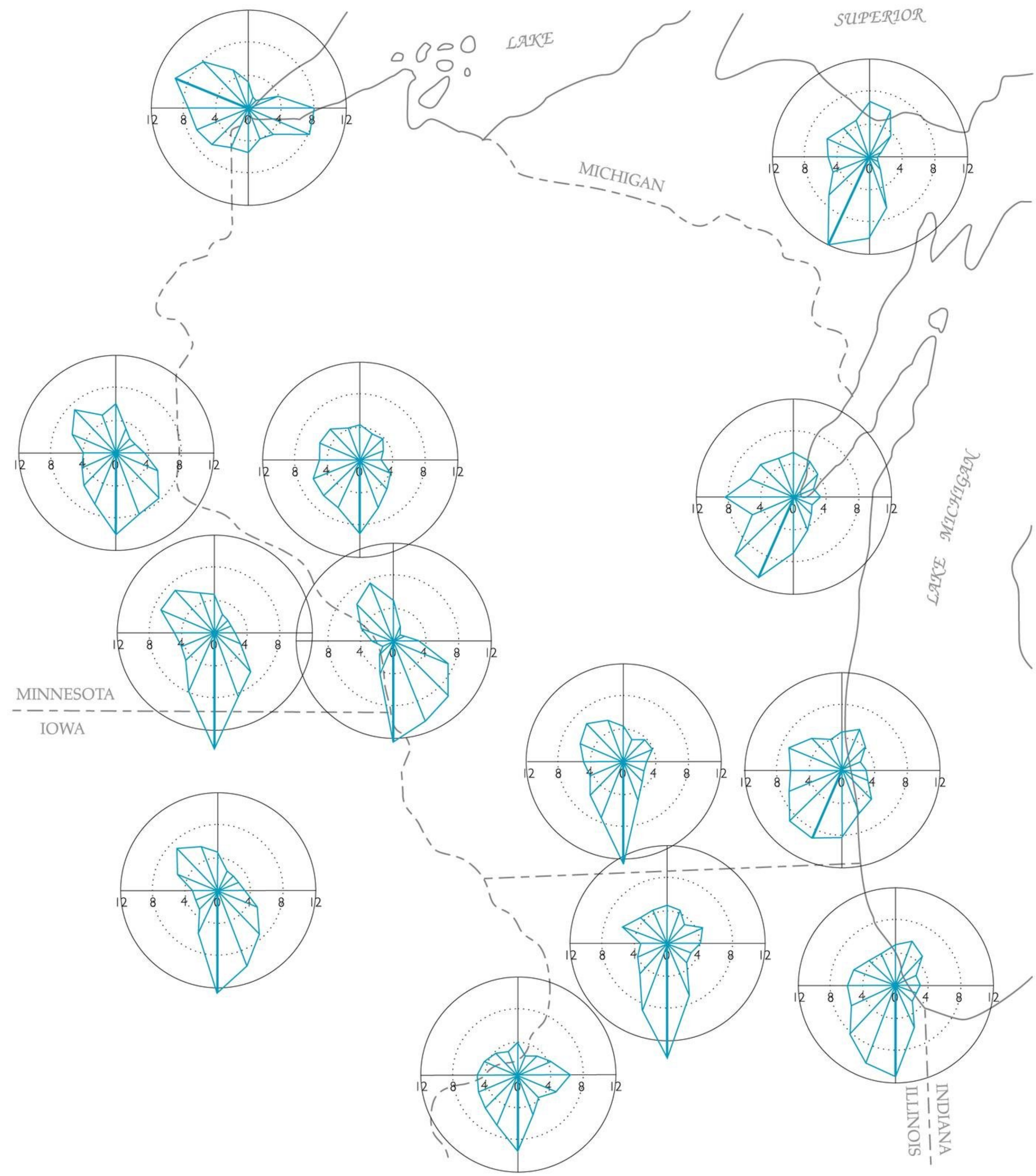
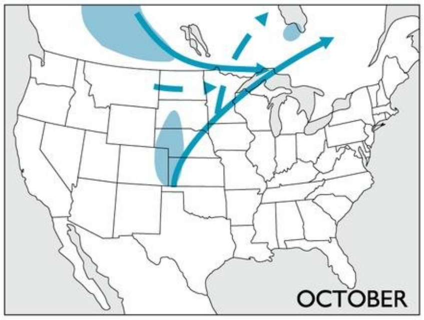


Figure 24. September wind roses for selected sites.



October. The frequency of winds from the south decreases at all but the most southern stations near Wisconsin in October and is replaced by the increased occurrence of west and northwest flow (fig. 25). Winds from the southeast continue to provide a significant part of the circulation at western stations. This may be partly a reflection of the locations of these stations in valleys oriented from northwest to southeast, which would tend to channel the wind into up-valley or down-valley flow.

Although the main storm track in October still lies near the northern border of Wisconsin, its exact position varies from year to year, and storms can travel across any part of the state. The primary flow of air is from the Pacific; this air is cool and moderately moist, although a significant amount of wind still blows north from the Gulf of Mexico and the southwestern United States. In October, temperature variations across Wisconsin are at the minimum for the year, reflecting the lack of contrast in temperature between land and lakes. The lake breeze component of wind at the lake-shore stations is relatively small in this month.

Wind speeds at all stations continue to increase from their summer minima, and the percentage of calm conditions decreases as the weather becomes more active across North America and the upper Midwest (table 13). Peak gusts this time of year may be related to intense thunderstorms, but can also occur in strong low-pressure systems in the strong winds behind cold fronts.

Table 13. *October wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	9.7	S 10.4	7.8	45.0	7.4	62 NW	1990
Milwaukee	11.4	SSW 12.1	2.5	43.4	5.1	53 NW	1990
Green Bay	10.0	SW 11.2	4.0	39.0	4.1	46 NW	1976
						SW	1980
La Crosse	10.4	S					
Eau Claire	10.0	S					
Duluth	11.4	NW 12.4	2.6	46.1	8.9	70 NW	1987
Minneapolis	10.6	NW 13.2	3.6	44.2	4.8	53 NW	1987
Rochester	12.2	S 13.6	3.6	50.8	6.1	62 N	1985
Waterloo	10.1	S 11.7	6.4	45.8	3.5	49 N	1987
Moline	9.4	S 11.8	10.2	44.9	6.9	61 SW	1984
Rockford	9.7	S 9.5	6.3	44.2	7.0	59*	1979
Chicago	9.9	S 10.4	3.3	40.9	6.3	58 SSW	1971
Sawyer/Gwinn	9.9	SSW					

* not reported

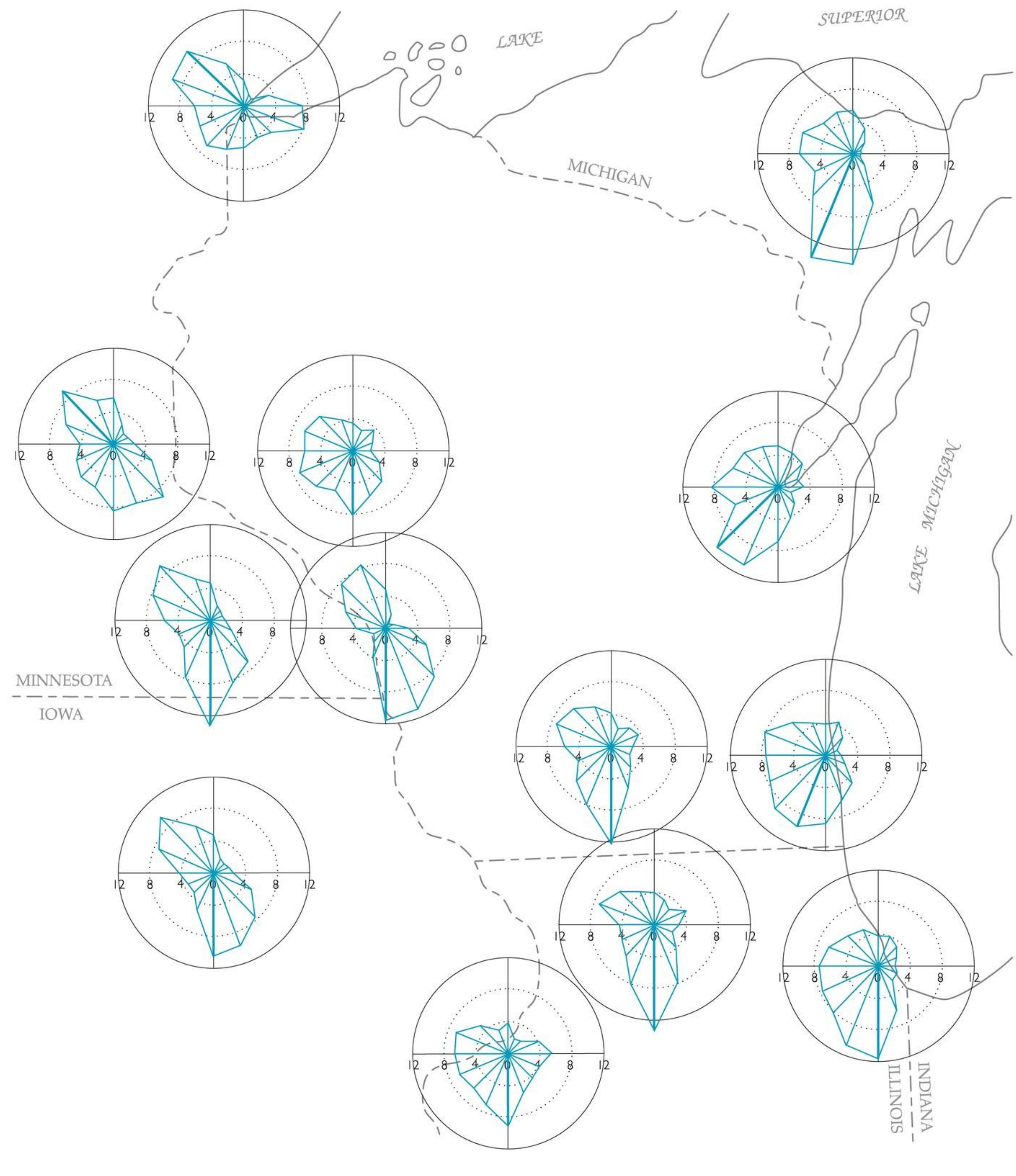
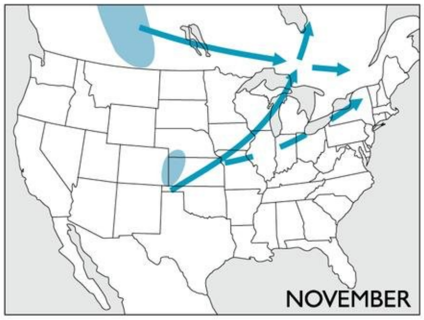


Figure 25. *October wind roses for selected sites.*



November. In November, the winds increase to their strongest intensity of the fall as the regional differences in temperature between north and south approach their maximum (fig. 26). Average wind speeds surpass their October values by 0.5 to 1 mph (table 14). The percentage of calm conditions remains low, particularly at lake-shore stations and the exposed station at Rochester, which is known for its windy conditions.

Even though the number of storms passing south of Wisconsin increases in November, the easterly component of the winds decreases from October. Prevailing winds at most western locations are now from the west to northwest; southerly winds still dominate in the southeast. Air from the Arctic enters Wisconsin more frequently, bringing with it colder temperatures and drier conditions, particularly in the north. In the south, the source of most air is still the Pacific; Pacific air is milder in temperature and higher in humidity than Arctic air.

Typically, early winter conditions and the first strong storms of the season occur in Wisconsin in mid-November, although heavy snowfalls associated with strong lows have occurred in northern Wisconsin in late October in some years. The Armistice Day storm of November 11–12, 1940, which resulted in $300,000 damage in Wisconsin and caused the deaths of 12 duck hunters, is one example of an extreme early winter storm.

Table 14. *November wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	10.8	S 10.7	5.7	44.4	6.2	55 W	1973
Milwaukee	12.3	WNW 13.1	1.8	46.6	6.1	56 SW	1988
						56 NW	1989
Green Bay	11.0	W 11.4	3.1	42.1	6.8	54 W	1975
La Crosse	10.9	S					
Eau Claire	10.7	WSW					
Duluth	12.0	WNW 13.9	2.6	43.1	6.1	54 NE	1974
						54 NW	1993
Minneapolis	11.0	NW 14.4	3.0	42.3	7.8	66 W	1986
Rochester	13.0	WNW 15.0	2.3	49.0	7.9	67 S	1977
Waterloo	11.2	NW 13.7	5.0	42.1	6.6	56 NW	1982
Moline	10.9	WNW 14.4	6.2	46.0	6.7	60 SW	1975
Rockford	10.6	S 10.0	4.4	43.5	6.2	59*	1988
Chicago	11.0	SSW 12.1	1.9	43.1	5.9	53 SSW	1964
						SW	1983
Sawyer/Gwinn	10.5	SSW					

* not reported

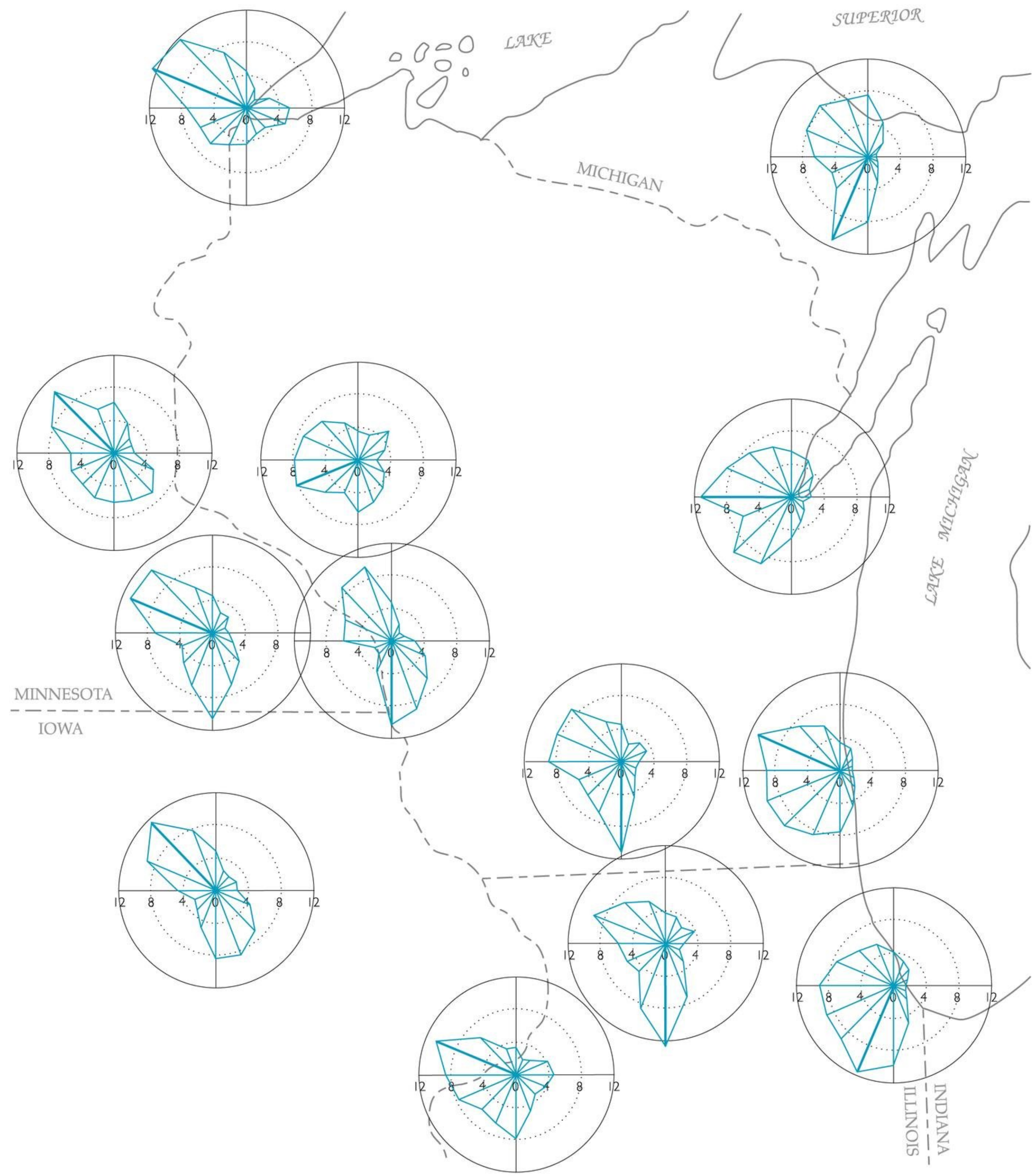
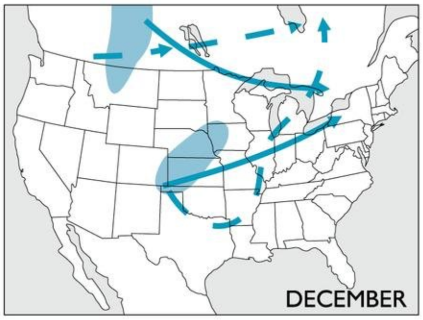


Figure 26. *November wind roses for selected sites.*



December. In December, west or northwest winds predominate at all locations except Eau Claire (west–southwest) and Sawyer (south–southwest) (fig. 27). Easterly winds are infrequent at most locations. Polar Canadian air occupies most of northern Wisconsin, but milder Pacific air affects southern Wisconsin with some frequency.

Wind speeds in December are slightly lower than their November values at most locations in the region, although winds are still frequent and strong (table 15). The percentage of calm conditions increases in the northern stations but decreases at southern stations from the November observations. This indicates the more frequent presence of Arctic high-pressure areas across northern Wisconsin; the southern locations are still subject to the effects of the lows traveling along the storm track. The highest wind gusts are usually associated with cold fronts trailing from strong low-pressure centers, and can cause momentary "white-out" conditions if snow is falling or is present on the ground.

As the cycle begins again in January, wind speeds will increase slightly from the December values listed below, but the percentage of calm conditions will remain almost identical. The storm track will continue to move southward, reaching its most southerly position in January.

Table 15. *December wind characteristics at selected sites*

Station	Average speed (in mph)	Prevailing direction and speed (in mph)	Calm (%)	Peak gust (average annual mean in mph)	Standard deviation of monthly mean	Record gust (in mph)	Year of record-gust occurrence
Madison	10.4	WNW 11.0	6.0	42.9	10.8	58 NE	1987
Milwaukee	12.3	WNW 12.4	1.4	47.3	6.6	61 N	1979
Green Bay	10.7	W 10.9	2.8	38.8	6.3	53 NE	1990
La Crosse	10.0	NW					
Eau Claire	9.9	WSW					
Duluth	11.6	NW 12.5	2.9	42.4	6.1	54 SW	1967
Minneapolis	10.4	NW 12.9	3.3	40.7	3.7	48 NW	1989
Rochester	12.9	NW 14.6	2.3	48.9	4.3	56 NW	1989
Waterloo	11.3	NW 13.3	4.2	44.7	5.3	53 NW	1985
Moline	10.8	WNW 13.9	5.0	48.8	8.2	69 SW	1975
Rockford	10.6	WNW 12.4	3.7	45.5	7.8	62*	1987
Chicago	11.0	W 11.2	1.8	42.7	8.1	62 S	1982
Sawyer/Gwinn	10.7	SSW					

* not reported

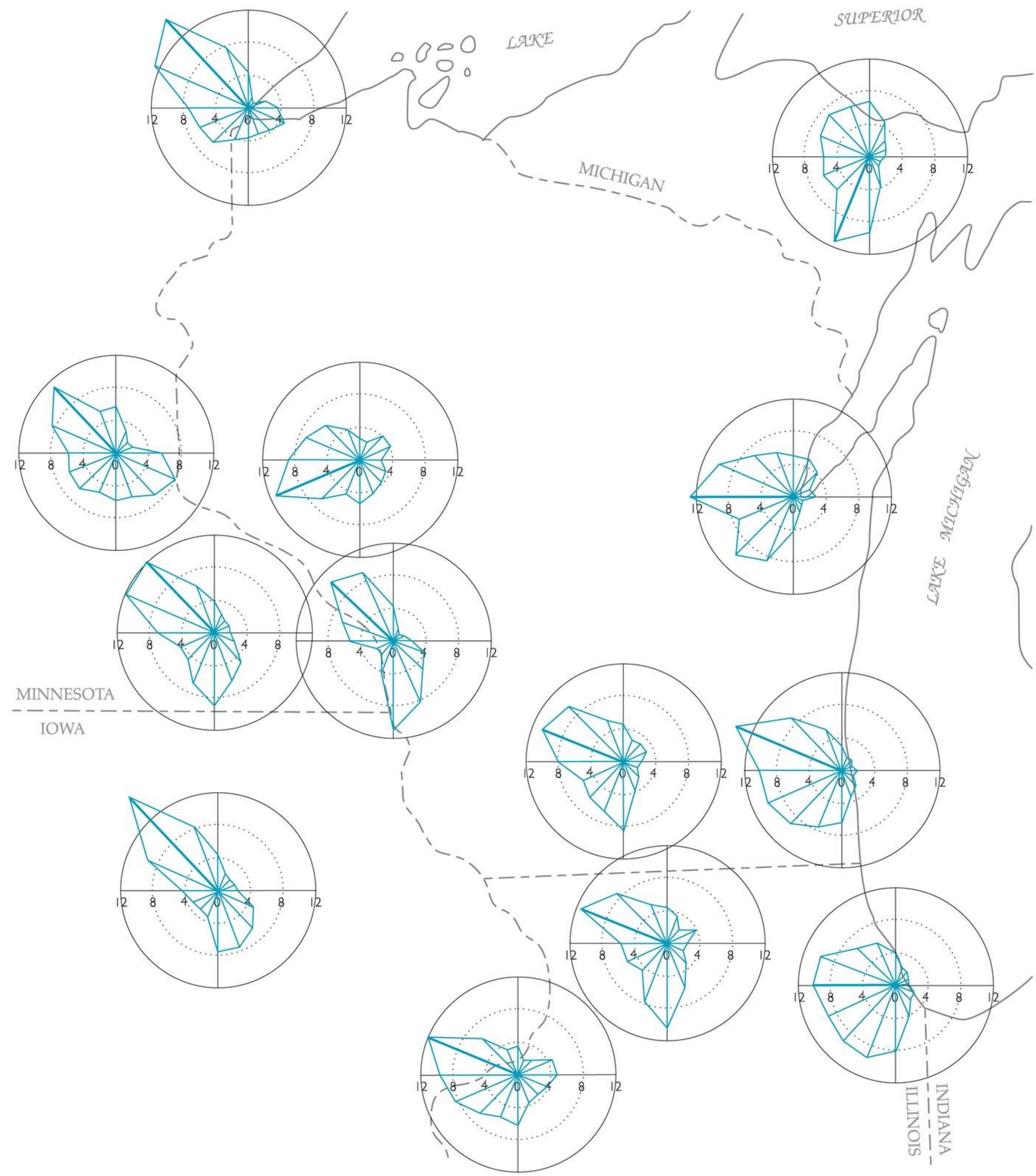


Figure 27. December wind roses for selected sites.

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