thunderstorm as severe if it has straight-line wind gusts of at least fifty-eight miles per hour. Straight-line winds cause the majority of thunderstorm wind damage and occasionally even reach 100 miles per hour, as we saw in Grosse Pointe Park on July 2, 1997, when a severe storm with wind at 100 miles per hour blew a gazebo into Lake St. Clair. Five of the thirteen people who sought shelter in the gazebo died.

Tornadoes

A more unusual type of thunderstorm is called the supercell, and most tornadoes come from supercells. Once the atmosphere is unstable enough to support powerful thunderstorms with violent updrafts, the next consideration is the wind environment the storm develops in: the storm needs changing wind direction with height (called wind shear) to support supercell characteristics. Here's how it works: Picture a storm with wind blowing from the southeast into the base of the storm. A few thousand feet above the ground, the wind is blowing from the south. The wind is blowing from the southwest by the time you get up to 10,000 feet and, finally, from the west at 15,000 feet. This veering of the wind with height supports air that spirals upward in the storm, eventually causing rotation within the storm.

But what turns that rotation into the violent winds of a tornado? It's another one of those laws of physics, the conservation of angular momentum, and if you have ever seen a figure skater on ice, then you have this one down pat. The law states that if an object of a certain mass is spinning and its diameter gets either larger or smaller, then its speed *must* adjust accordingly. For example, when a figure skater starts her big spin, you will notice her arms (and even one leg) extended out from her body. As she slowly begins to bring her leg and arms in, her speed rapidly increases. If you want to try this yourself, sit in a chair that spins, with arms out to your side, holding a brick or large book in each hand. Get yourself spinning and quickly bring your arms in to your chest: you'll notice an immediate (albeit brief) acceleration in the speed of your spinning.

Now, think about that rotation in the storm. Something causes the vortex to stretch and narrow. As this happens, the law of conservation of angular momentum requires a corresponding increase in the speed of the

rotation, and the stronger the wind in the storm is, the stronger the potential winds of the tornado. Most tornadoes are weak, with winds less than 110 miles per hour. However, the rare strongest twisters can produce wind well over 200 miles per hour.

Although most tornadoes come from supercells, some do not. Sometimes, wind interactions between two severe thunderstorms in close proximity to each other cause enough wind shear to spin up tornadoes. Additionally, an approaching line of severe thunderstorms sometimes develops waves or kinks, and the resulting change in low-level wind is enough to generate a tornado. This type of nonsupercell tornado is often referred to as a "gustnado" by meteorologists and is normally weaker than supercell tornadoes and brief in nature.

One other nonsupercell tornado is the fair-weather waterspout, which is most common over the Great Lakes in late summer and fall, when lake temperatures are still relatively warm and when cool, moist air masses begin moving in. Fair-weather waterspouts are generally smaller, briefer, and less violent than supercell tornadoes. However, they still pose a significant threat to boaters nearby and occasionally cause damage if they move ashore.

Fortunately, Doppler radars, which have been used operationally since the 1980s, allow us to see wind inside of developing supercells. Raindrops are targets seen by the radar, and these targets are carried by wind in the storm. The radar sends out a pulse that travels at a specific frequency. When it bounces off raindrops moving toward the radar, the reflected pulse's frequency is shifted a little higher; when it bounces off raindrops moving away from the radar, the reflected pulse's frequency is shifted a little lower. The radar's computer determines the amount of frequency shift and correlates this to a wind speed. So, meteorologists can see both wind speed and direction inside the storm, which gives us the ability to identify strong rotation in developing supercells.

Tornadoes in Michigan

Before discussing Michigan tornadoes in greater detail, it is important to know that the United States receives **95 percent** of the world's tornadoes. "Tornado Alley," as the central United States is sometimes called,

is uniquely positioned between the Gulf of Mexico to the south and a large landmass to the north. Warm, moist air surges northward from the gulf, while cool, dry air pushes south from Canada, and where the two collide creates a type of storm not often seen in most other parts of the world. It's like putting matches and gasoline in the same room. You know that something bad will eventually happen.

Most people grossly misunderstand the tornado threat in Michigan. It is true that we don't receive nearly as many tornadoes as Texas and Oklahoma, and because of this, some people think that tornadoes are not a serious threat here. This could not be further from the truth. Tom Grazulis conducted the most comprehensive historical and statistical study of tornadoes in American history, and his publication *Significant Tornadoes* provides tremendous insight into Michigan tornadoes.

For example, the top five states in total number of significant tornadoes received from 1880 through 1989 are Texas, Oklahoma, Kansas, Arkansas, and Iowa (Grazulis defines a "significant" tornado as any tornado rated F2 or greater on the zero-to-five Fujita scale or an F0 or F1 tornado that caused a fatality). Where did Michigan rank? Eighteenth. This is not the whole story, however. Weather patterns shift, and there are times when we are much closer to the bull's-eye. For example, from 1953 through 1989, Michigan ranked *fourth* nationally in tornado deaths. During this same period, Michigan ranked *eighth* nationally in the number of violent (F4–F5) tornadoes as a percentage of all tornadoes received, while Texas ranked twenty-seventh. What does this mean? While Texas received more overall tornadoes than we did here in Michigan during this period, there was a greater chance that any tornado occurring here would be particularly violent. This is significant because although only 1 percent of all tornadoes are violent, two-thirds of all tornado fatalities are caused by this 1 percent of tornadoes.

The greatest tornado threat in Michigan occurs in the southern part of the state, which experiences warm, humid air more frequently than areas farther north. However, *since the modern era of tornado statistics began in 1950, every single county in Michigan has experienced at least one tornado.* It is important that those who live "up north" respect the tornado threat, and history bears this out. On April 3, 1953, an F3 tornado with winds between 136 and 165 miles per hour moved through Manistee, Benzie,

TABLE 2. F5 Tornadoes in Michigan

F5 TORNADO DATE	COUNTIES	KILLED	INJURED
May 25, 1896	Oakland/Lapeer	47	100
June 5, 1905	Tuscola/Sanilac	5	40
June 8, 1953	Genesee/Lapeer	115	844
April 3, 1956	Allegan/Ottawa/ Kent/Montcalm	28	340

Grand Traverse, and Leelanau counties, killing two and injuring twenty-four. Just two months later, an F2 twister struck Iosco County, killing four and injuring thirteen. More recently, on July 4, 1986, an F3 tornado touched down in Wisconsin and traveled into Menominee County, injuring twelve people.

And what about those rare F5 tornadoes glorified in the movie *Twister*? Do those happen here? You bet they do. Michigan has been struck by *four* F5 tornadoes since 1880.

The tornado that hit the Flint suburb of Beecher on June 8, 1953, is one of the most notorious tornadoes in our nation's history. This tornado is the ninth deadliest twister ever in the United States and still reigns as the last single tornado to kill more than 100 people in America (see fig. 3). An F5 tornado will strike again somewhere in Michigan. It's a matter of not if, but when. And contrary to popular belief, tornadoes do not shy away from major metropolitan areas. Just since 1980, a tornado roared right up Main Street in downtown Kalamazoo, and two tornadoes hit the city of Detroit. Making matters worse, urban sprawl is creating bigger "targets" for tornadoes.

Finally, although Michigan tornadoes are most common during the afternoon hours in late spring, summer, and early fall, you need to keep your guard up even during "nontraditional" times of the day or year. On October 18, 2007, eleven tornadoes struck our state (the fifth most for a single day since 1950), and most of them occurred after dark (see fig. 4). Coincidentally, just six years earlier, nine tornadoes touched down in Michigan on October 24, 2001. And what about winter? Although severe weather in the middle of winter is highly unusual here, it occasion-

ally develops if we end up on the warm side of a powerful storm system and if the proper ingredients are in place.

Tornado Safety

The most important thing to remember about tornadoes is that there are things you can do to significantly enhance your chance of surviving a close encounter. Most people hurt or killed by tornadoes are not picked up by the twister and thrown somewhere. Rather, flying debris causes most tornado casualties. Think about it: if an ordinary digital camera becomes airborne in a tornado and strikes you at 135 miles per hour, the camera wins this battle, and you lose. So any tornado safety plan should minimize your exposure to flying debris.

First, take advantage of the advance notice afforded by tornado watches. A tornado watch simply tells you to "watch out." It can be a perfectly sunny day when the watch is issued, but all of the ingredients necessary for severe thunderstorms and tornadoes may come together within the next few hours, and this is the only long-term notice you will have. It is your time to plan and prepare. Make sure your flashlights and radios have working batteries, in the event the power goes out. Also check that everybody with you knows where all of you will go for safety if a tornado threatens. This is also a good time to check on any elderly neighbors and relatives and make sure they are aware of the situation.

A tornado warning is an urgent situation, because this means either that a tornado has been spotted or that Doppler radar has identified a thunderstorm capable of producing a tornado. Tornado warnings are now issued for specific areas in immediate danger. This new process, called storm-based warnings, began October 1, 2007, and issues warnings in polygons based on the storm path, rather than for an entire county. There are many ways you may find out about the warning: sirens, television, commercial radio, NOAA Weather Radio All Hazards broadcasts (provided by the National Oceanic and Atmospheric Administration), the Internet, or even personally observing the approaching storm. Incidentally, the current version of weather radios allow you to program them just to alert you to warnings in *your* county, so you are

not bothered by warnings for other areas. You need to take cover without delay when a tornado warning is issued for your area, and I practice what I preach.

Late one summer day, when my oldest son, Jared, was about five months old, I was home alone giving him a bath when my neighborhood tornado siren suddenly went off. I did not go outside to take a look, nor did I check the computer to see what was going on. I immediately wrapped Jared in a towel, grabbed his clothes and my weather radio, and rushed right for the basement. When that siren went off, all I knew was that my county was under a tornado warning, and I had no idea if a tornado was twenty-five miles away or the next street over. I heard on the weather radio that an isolated storm had developed and that Doppler radar detected strong rotation within the storm. The storm was over the opposite end of the county and not moving toward me, so I was not in any danger. The moral to this story is that I remembered what happened to the two women you read about at the beginning of this chapter, and I was not about to take any chances with my son.

If a tornado threatens, here is what you need to know.

1. The general rule of thumb in a building is to go to the basement if it has one and to take cover under a table or in a small room down there. *Stay away from windows.* If you are old enough, you probably remember a time when we were told to open the windows before a tornado strikes. This was later determined to be wrong, because taking the time to open windows not only delays getting to your place of safety but also doesn't help.
2. If you are in a building without a basement, go to a small room in the center of the building's lowest floor. A bathroom is great (as long as it doesn't have windows), because pipes in the walls give you some added protection. A small closet or pantry in the interior of that lowest floor also works well.
3. If you are in a car when a tornado warning is issued for the county you are in and you do not see any particularly threatening weather nearby, then rush to the nearest sturdy building to take cover. If you see a tornado, then you have a decision to make. If

the tornado is distant and traffic allows, drive away from the storm at right angles to the direction the tornado is moving and get to a sturdy building for shelter. If the tornado is close and heading toward you or if traffic is jammed and does not allow an escape, *exit the vehicle immediately* and lay in a low spot, such as a roadside ditch (this helps protect you from flying debris). *Do not take cover on the elevated sides of a freeway under the edge of a bridge.* Even though a very famous video shows a television news crew apparently surviving a tornado under a freeway overpass, the tornado actually passed nearby. If that tornado had moved closer to where they sought shelter, then flying debris may have impaled them there.

4. Like cars, mobile homes offer no protection whatsoever from tornadoes. If you live in a mobile home community, then you need to have a tornado safety plan that involves sturdier shelter than your mobile home. Whether it is a storm cellar or permanent building in your community or a nearby house, store, or other building, you need to pay particular attention after the tornado *watch* is issued, so that you have time to move to sturdier shelter when (or, better yet, before) the tornado *warning* is issued.
5. Boats, obviously, are a very dangerous place to be in severe storms and tornadoes and, at a minimum, serve as lightning rods even in "routine" storms. It is vitally important to check the weather forecast before heading out and to have a weather radio with you to keep you abreast of special marine warnings issued by the National Weather Service. More and more boaters either have radar on board, computers with which they can watch the radar on the Internet, or radar on their cell phones and PDAs. So boaters today can monitor approaching weather like never before. Keep an eye to the sky, and head in at the first sign that a storm is approaching.
6. Finally, my greatest fear as a meteorologist is of a tornado striking a school during the school day. Public schools are supposed to conduct periodic tornado safety drills, but did you know that as recently as 1998, Michigan schools were not required to? I

learned this at a meeting of the Michigan Committee for Severe Weather Awareness (MCSWA), and I was later able to get legislation introduced to amend state law so that these drills would be required. I testified before the state House and Senate education committees about the tornado threat in Michigan and joined Governor John Engler when the "Gross Weather Bill" (get it?) was signed into law. Now, every public school in Michigan is required by law to conduct a *minimum* of two tornado safety drills per year, preferably one just after the beginning of the school year and another in the spring. Go to the MCSWA Web site at **http://mcswa.com** for more information about setting up a tornado safety plan at your school, but there are two vitally important things I will tell you right here. First, have a battery powered NOAA-approved weather radio in the main office, change its batteries twice a year, and *keep the radio turned on in alert mode at all times* (you would be surprised at the number of schools that have their weather radios turned off when I visit). Second, have a way to communicate when the power goes out. Most schools today have intercom systems that go silent if a storm knocks out power. Battery-powered walkie-talkies and megaphones are critical should an emergency occur and you have no power.

Although no tornado safety plan guarantees absolute safety from a direct hit, history proves that the above safety tips greatly increase your chance for survival. Commit these rules to memory.