

SUPERCELLS - Nature's Violent Thunderstorm

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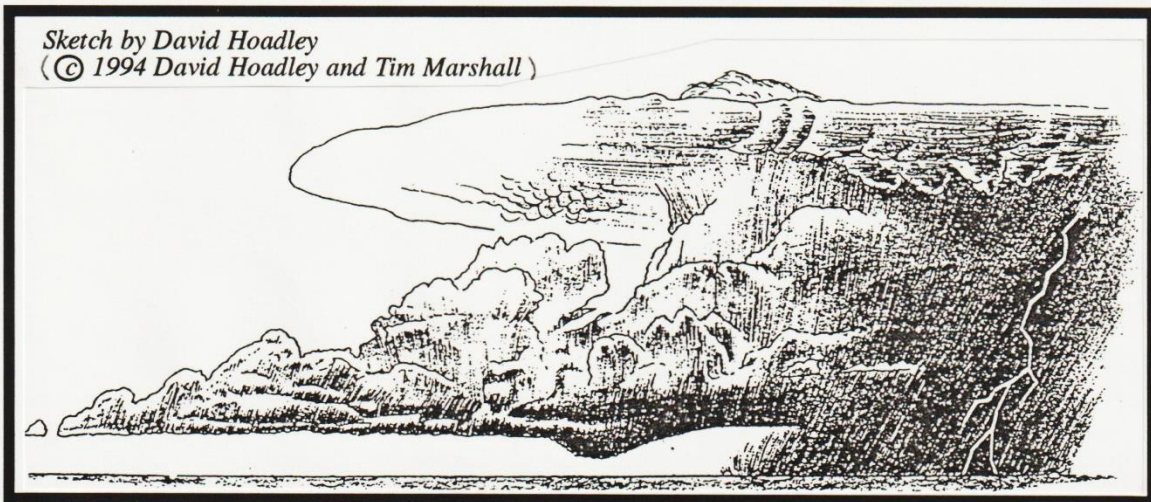
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- **March 27, 1994, Piedmont, Alabama**
20 people were killed and more than 90 injured when a tornado struck a church on Palm Sunday morning.
- **July 11, 1980, Denver, Colorado area:**
The worst hailstorm in United States history injured 60 people at an amusement park. Hail up to baseball size caused over \$600,000,000 in damage.
- **July 1, 1985, Cheyenne, Wyoming:**
A slow-moving supercell brought on flash flooding from 8 inches (20 cm) of rain, and also dumped piles of hail up to one foot deep. Sixteen people were killed, with \$67,000,000 in damage.

Introduction

What do these disasters have in common? All were caused by a dangerous but infrequent type of thunderstorm known as a **supercell**. More than 100,000 thunderstorms occur every year in the United States. Of these, meteorologists estimate that 2000 to 3000 are supercell thunderstorms.

Although less than 5% of all thunderstorms are supercells, they cause a disproportionate amount of deaths, injuries, and property damage related to severe weather. Virtually all strong and violent tornadoes (Table 1) are spawned by supercell thunderstorms. Supercells can also produce large hail, damaging winds, and torrential rains that may lead to flash floods.

TABLE 1. Tornado F-scale intensity (after Fujita, 1987).

F-Scale	Miles/hour	Meters/second	Category	Intensity
F-0	40-72	18-32	Weak	Light
F-1	73-112	33-50	Weak	Moderate
F-2	113-157	51-70	Strong	Considerable
F-3	158-206	71-92	Strong	Severe
F-4	207-260	93-116	Violent	Devastating
F-5	261-318	117-142	Violent	Incredible

Supercells are rarely mentioned in middle or high school textbooks and teaching materials, or by the media. But supercell thunderstorms pose a significant threat to life and property, particularly east of the Rocky Mountains. This paper is intended as a resource for science teachers and their students to become better informed about supercell storms. Atmospheric processes capable of

producing supercells are described, as well as how meteorologists identify supercells on radar. Information is also provided on visual clues for identification of supercells, and how to react to National Weather Service warnings. Such education and preparedness can minimize the impact of severe weather on activities at school and at other locations. A paper with the same goals was published on lightning (Vavrek et al., 1993a,b; 1994).

Supercell Thunderstorms

A supercell is a thunderstorm with a main updraft that is **persistent** and **rotating**. While all thunderstorms are composed of updrafts and downdrafts, a supercell has a dominant parent updraft that can persist for hours. Due to its rotation and 'balanced' structure, this updraft can resist interference from surrounding downdrafts to continue much longer than a normal thunderstorm updraft or 'cell'. The result is that supercells usually become stronger and last longer than typical thunderstorms.

Some supercells persist for several hours, traversing parts of two or more states while producing severe weather. In contrast, non-severe thunderstorms typically last less than an hour. Several types of severe weather can occur with supercells:

- Tornadoes
- Winds exceeding 57 mph (20 meters per second)
- Hail 3/4 inch (2 cm) or larger in diameter
- Intense rainfall that can lead to flash floods
- Deadly lightning

Supercell thunderstorms are often large and tall, extending to heights of 50,000 to 65,000 ft (16 to 20 km), particularly during late spring and summer. However, other supercells can be smaller (height less than 40,000 ft, or 13 km) and still produce significant severe weather.

Supercells are most common during spring and summer in the late afternoon and evening east of the Rocky Mountains. This is where weather systems with favorable wind conditions have better access to warmth and moisture from the Gulf of Mexico. However, supercells are not uncommon during other months and times of day. For example, in the Gulf and southeastern states, conditions favorable for supercells occur most often during winter and early spring in the late night or early morning hours.

Supercells can also occur over a variety of terrain. A supercell near Yellowstone National Park in Wyoming during July 1987 produced a tornado and damaging straight-line winds across rugged terrain at 10,000 ft (3 km) elevation. Contrary to local legends and myths, it is important to remember that hills, valleys, rivers, and lakes have little or no effect on severe weather produced by supercell thunderstorms.

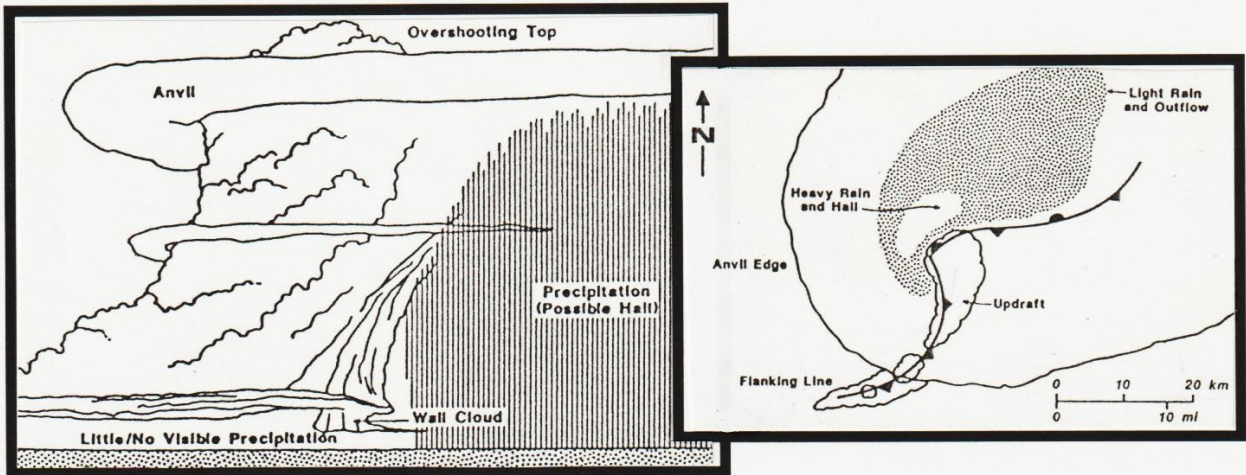


FIGURE 1: Idealized views of a classic supercell (from Doswell et al., 1990): (a) Ground-based view looking toward the northwest from a location southeast of the storm. (b) Overhead schematic view of structure.

Supercell Development

Supercell thunderstorms begin much like any other thunderstorm. A rising column of warm, moist, and unstable air, initiated by the sun's heating or upward lifting in the atmosphere, cools and condenses into cloud and precipitation droplets. As this updraft builds to greater heights, a thunderstorm develops. Supercells usually require strong updrafts that develop in a very unstable environment where warm, moist air near the ground is overlain by cold, dry air in middle levels of the atmosphere.

A major difference between supercells and other thunderstorms is the surrounding **wind profile**: the winds at different levels encircling the storm are arranged in a way that can cause a thunderstorm updraft to rotate. The most favorable wind profile for producing this rotation begins with winds from a southerly direction at the ground. Then, as one moves upward, winds increase in speed and become more westerly with height, particularly in the first 6000 to 9000 ft (2 to 3 km) above ground. If it were possible to suspend a huge football in this layer, it would begin to spin or spiral, similar to a football thrown by a quarterback. Because of this, we can say that this arrangement of winds contains 'spin'.

If a thunderstorm develops and builds within this type of wind environment, some of this 'spin' will be fed and tilted into the thunderstorm's updraft, which may cause the updraft itself to start rotating. It might help to visualize a spiraling football thrown downfield that is suddenly pulled upward into a rapidly rising column of air; the football will be tilted from a horizontal to a vertical axis while it continues to spin. In a similar fashion, the thunderstorm updraft begins to spin about a vertical axis as air containing 'spin' from the surrounding wind profile is tilted upward into the updraft. A rotating updraft can more readily withstand surrounding downdrafts and

other forces that would soon destroy an ordinary non-rotating thunderstorm updraft.

Winds in the middle levels of the atmosphere (10,000 to 20,000 ft, or 3 to 7 km above ground) are also important. It is no coincidence that supercells tend to occur with weather systems that are in close proximity to jet stream winds aloft. If these winds are moderate to strong, they help to move precipitation downwind and away from the main updraft, which reduces precipitation and downdraft interference with this rapidly rising and rotating column of air. This serves to further strengthen and balance the rotating main updraft so that it can persist much longer than a typical thunderstorm updraft.

In some powerful supercells, this balance is such that updrafts with vertical speeds of over 100 mph can develop. Storms with such strong updrafts will almost invariably produce severe weather, including tornadoes.

Types of Supercells

There are different types of supercells that vary in appearance visually and on radar. For example, some supercells can be isolated, while others may be embedded in a line or cluster of thunderstorms. Furthermore, many supercells transition from one type of appearance to another during their life cycle. The following general types or categories of supercells have been recognized and identified by meteorologists:

- **Classic supercells**

As shown in Figure 1, classic supercells typically have a well-defined area of precipitation just north of the cloud tower or main updraft. Beneath the main updraft and just south of the precipitation is a rain-free base, with a lowering or rotating wall cloud evident beneath this base. Classic supercells are usually isolated.

- **LP (Low-precipitation) supercells**

In the High Plains where moist air from the Gulf of Mexico comes along side drier desert air from the western United States, some supercells produce very little precipitation and are smaller in size (Figure 2). In spite of their benign appearance, these low-precipitation (LP) supercells can produce significant severe weather.

- **HP (High-precipitation) supercells**

As seen in Figure 3, high-precipitation (HP) supercells produce more precipitation than classic or LP types. Rain and hail often eliminate much of the rain-free base beneath the main updraft. Features such as lowerings or rotating wall clouds may be obscured by rain, and tornadoes may be difficult if not impossible to see. The deadly storms that produced the Plainfield, Illinois tornado on August 28,

1990 and the Catoosa, Oklahoma tornado on April 24, 1993 were HP supercells with tornadoes obscured by rain.

Although HP supercells can occur in isolation, they are more often embedded in lines or clusters of thunderstorms (see Figure 4). Recent radar observations have shown HP supercells to be more common than previously thought. In the eastern U.S., they are considered the predominant type of supercell. Flash-flooding that occurs with supercells is most often associated with HP storms.

- **Hybrid supercells**

Many supercells display features of more than one of the above types at different stages in their life cycle, and do not fit neatly into one category. Such hybrid storms are a reminder that supercells in progress are constantly evolving, and are part of a continuous spectrum of thunderstorm types.

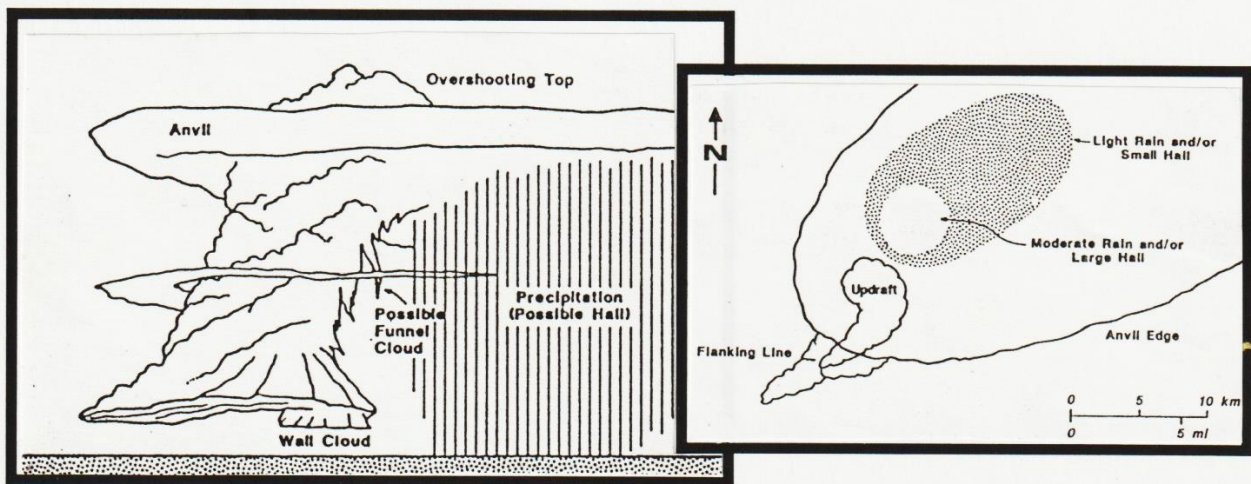


FIGURE 2: Idealized views of a LP (low-precipitation) supercell (from Doswell et al., 1990): (a) Ground-based view looking toward the northwest from a location southeast of the storm. (b) Overhead schematic view of structure.

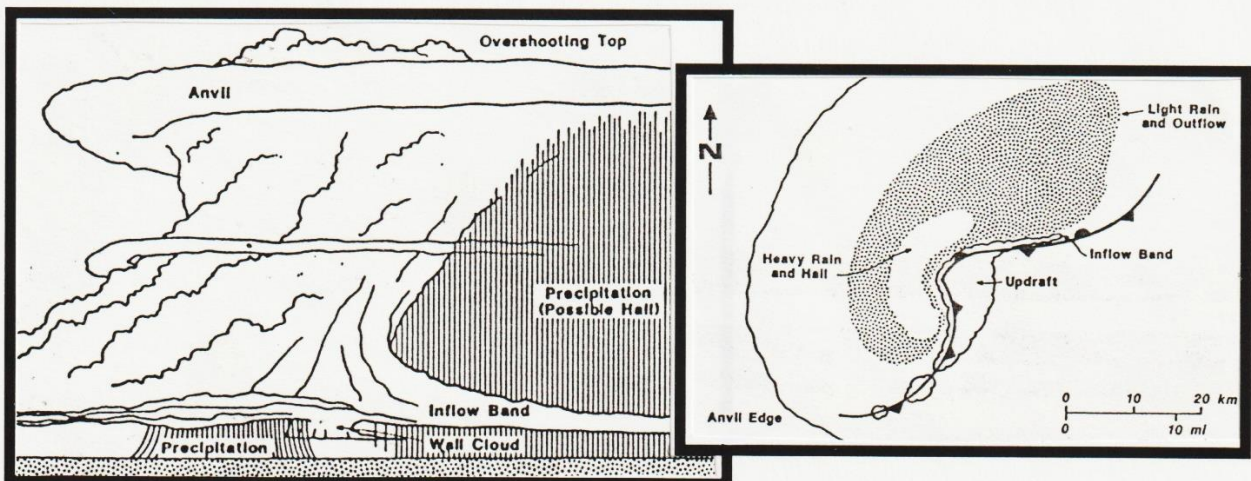


FIGURE 3: Idealized views of a HP (high-precipitation) supercell (from Doswell et al., 1990): (a) Ground-based view looking toward the northwest from a location southeast of the storm. (b) Overhead schematic view of structure.

Supercells on Radar

Radar is an indispensable tool for detecting and observing supercell thunderstorms. Radar detects precipitation by sending short bursts of electromagnetic energy into the atmosphere. A small portion of this energy is reflected back to the radar by precipitation particles. This energy reflected back, which is called **reflectivity**, is commonly displayed as maps showing the location and intensity of precipitation-producing clouds and storms (see Figure 4). In the past, supercells have been identified indirectly by recognizing shapes or patterns of reflectivity such as 'hooks' and 'backward commas' that have been found to sometimes accompany supercells.

A new generation of 140 radars using Doppler capability will be installed by 1996 across the U.S. by the National Weather Service and Department of Defense. This new Doppler radar (called WSR-88D) is a much improved tool for detecting supercells. This is because Doppler radar, in addition to measuring reflectivity, has the ability to detect *moving particles* of precipitation by measuring the Doppler frequency shifts in energy reflected back. From the motion of these particles, speed and direction of winds within different parts of a storm can be measured. As a result, the new radars can directly detect the rotating updraft circulation as it develops within a supercell.

Mesocyclones

The rotating updraft circulation within a supercell as detected by Doppler radar is called a **mesocyclone**. A mesocyclone usually begins at mid-levels within a storm's main updraft, around 15,000 to 20,000 ft (4 to 6 km) above ground. While some thunderstorms may develop brief, shallow circulations, the key to identifying a supercell is *the persistence of rotation through a deep layer*. Radar meteorologists look for the rotation to be at least 10,000 ft deep and to persist a minimum of 10 minutes before identifying it as a true mesocyclone, and the storm as a true supercell. A typical supercell mesocyclone on radar has a diameter of 2 to 6 miles (3 to 10 km). Mesocyclones can be detected and tracked accurately within a distance of roughly 140 miles (225 km) from the radar site.

It is estimated that about 40% of mesocyclones produce tornadoes. A supercell's mesocyclone may spawn a tornado if:

- 1) The mesocyclone circulation extends downward toward the ground from its origin at middle levels, or develops within lower levels of the atmosphere, and
- 2) Other processes unfold that involve the interaction of downdrafts with the rotating updraft or mesocyclone.

If a tornado does develop, time between mesocyclone

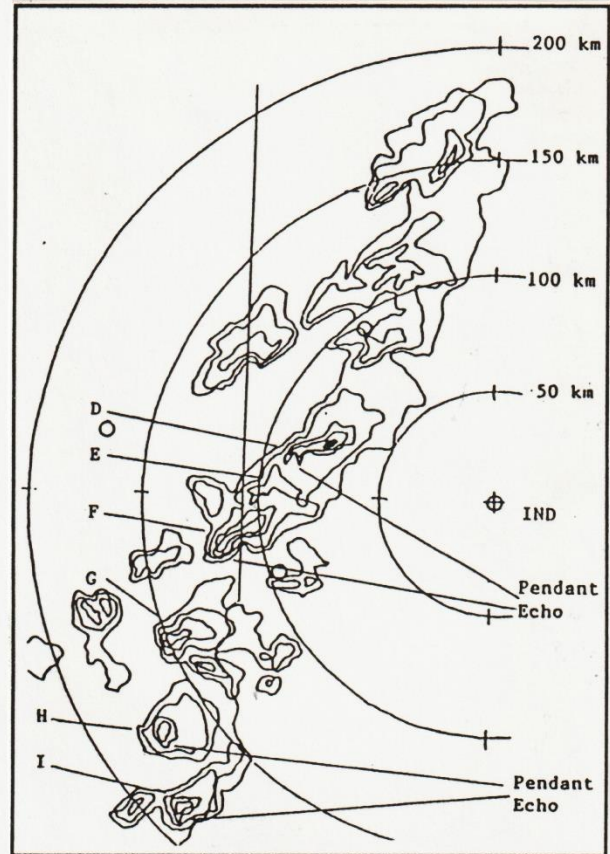


FIGURE 4. A line of thunderstorms with embedded supercells that produced 6 separate tornadoes at locations D through I. This is a view of reflectivity from the Indianapolis radar at 6:28 p.m. on June 2, 1990. Lines are contours of equal reflectivity. The north-south straight line is the Indiana-Illinois border (from Przybylinski et al., 1993).

development and tornado touchdown can be up to 20 minutes. This interval provides valuable lead time for warnings to be issued using radar data along the storm's path.

Unfortunately, it is not yet possible to predict which mesocyclones will produce tornadoes and which ones will not. There are complex factors involved, some of which are not yet understood by meteorologists. However, the Doppler capabilities of the new generation of radars do represent a significant improvement over the use of reflectivity alone for issuing tornado warnings. Even if tornadoes do not develop, the presence of a mesocyclone indicates that the storm is a supercell, and that there is a high probability of accompanying severe weather.

Visible Supercell Features

Most photography and visual documentation of supercells come from the Great Plains of the U.S. and Canada. This is because supercells are more common there, and are easier to see due to fewer trees and less haze as drier air aloft flows east from adjacent higher terrain.

Visual observations have also tended to focus on *isolated* supercells, which are easier to observe because there are no other thunderstorms nearby to interfere with viewing. It is important to remember that many supercell features, particularly in the eastern half of the United States, may not be visible due to haze, cloud cover, trees, hills, nearby precipitation or adjacent storms. Doppler radar, as discussed in the previous section, is invaluable in such circumstances.

The following features of a *classic isolated supercell* (Figure 1) are apparent under the best viewing conditions:

Tower: A sharply outlined main cloud tower is above the south or west flank of the storm, indicating the main updraft.

Anvil: A flat anvil composed of ice crystals tops the cloud tower, and extends downwind with the upper level winds in the direction of storm movement, which is usually to the east, northeast or southeast. The anvil indicates the point at which rising air in the main updraft has reached the stratosphere (a stable layer at high levels in the atmosphere) where further upward growth is stopped. Sometimes a 'back-sheared' anvil will build upwind a short distance over the west or southwest flank of the storm.

Flanking line: A line of towering cumulus clouds extends to the southwest, 'stair stepping' down from the main cloud tower or updraft.

Rain-free base: Underneath the main cloud tower or updraft, a cloud base that appears distinct and rain-free extends south of the precipitation and runs southwest along the flanking line.

Wall cloud: This is a lowering of cloud under the main cloud tower and rain-free base, and represents the bottom of the main updraft. *It may show rotation*, and is often very close to rain and hail falling to the north. Sunlight may be visible immediately south or west of the wall cloud, where a downdraft sometimes clears out clouds behind the storm. About half of all wall clouds produce tornadoes, and winds under the wall cloud may be intense, so this area should be watched carefully.

Recalling other supercell types from an earlier section, rain-free base and wall cloud features with *low-precipitation (LP) supercells* (Figure 2) will often occur while little or no visible precipitation falls from the storm. In contrast, rain and hail in *high-precipitation (HP) supercells* (Figure 3) may extend so far south under the main updraft that there is no rain-free base, and wall clouds may be obscured or difficult to see.

Remember that dangerous lightning may be present in and near the supercell. Also remember that an absence of lightning activity does not mean that the storm won't produce severe weather.

The National Weather Service provides training classes on identifying or 'spotting' severe weather. Law enforce-

ment officials, firefighters, emergency management personnel, amateur radio operators, and others attend these classes. Timely detailed reports from these Skywarn spotters regarding cloud features and severe weather are used in conjunction with Doppler radar by National Weather Service (NWS) meteorologists to issue severe weather warnings.

Teachers, coaches, bus drivers, and other school personnel, as well as officials from hospitals, nursing homes, and other business and industry can also benefit from spotter training. By posting a lookout or spotter near your building when severe weather threatens, personnel and students can be quickly alerted to an approaching tornado or other severe weather. Contact your local NWS office, county emergency management office, or local ham radio club for more information.

Safety Precautions

When severe weather from supercells or other strong thunderstorms is expected in your area, the best way to stay informed is to listen to NOAA Weather Radio or a commercial radio or television station that provides full coverage of severe weather statements and warnings.

Determining whether an approaching thunderstorm is severe may be difficult from visual clues alone, especially when a high-precipitation (HP) supercell is involved. By the time precursor severe weather events are near, it may be too late to seek shelter. **Be sure to do the following:**

- React quickly and properly to warnings from broadcasts, community or school sirens, or other alert systems in your area. Remember that many sirens are designed only as outdoor warning systems, and may not be audible indoors.
- Have ready a predetermined preparedness plan, and be prepared to follow it *immediately*.
- When threatening weather approaches, go to the interior part of a strong building on the lowest floor, such as a basement. Put as many walls between you and the outside as possible, and avoid corners. When there is no basement, go to an interior room against the strongest wall.
- Mobile homes and automobiles are very vulnerable to high winds and tornadoes, and should be abandoned in favor of a sturdy shelter. If none is available, as a last resort, seek shelter in a ditch. Around 40% of tornado deaths occur in mobile homes.
- Cover your head with a heavy blanket or pillow to protect against flying debris that can kill or injure.
- Take special precautions for the young, old, and those with physical or mental impairment.

Despite great advances in meteorology and improved technology for supercell identification during the last decade, severe weather can develop so rapidly that warnings may not reach you in time. It is also possible that you

may be in a position where you are not able to hear a warning. In such cases, stay alert, use common sense, and pay attention to visual clues. Severe weather from supercells or other strong thunderstorms may threaten when the following are visible:

- Large thunderstorm towers with well-defined anvils
- Cloud bases that are dark, low-hanging, and some times tinged with green.
- Rotating clouds
- Hail
- Frequent lightning
- Torrential rain

For additional safety information, contact your local National Weather Service, American Red Cross, Civil Defense, or Emergency Management Center or office.

Conclusion

Supercell thunderstorms pose a significant threat to lives and property in the United States. While they represent a small percentage of all thunderstorms, supercells are responsible for a large percentage of injuries, deaths, and property damage that occur from thunderstorms.

Supercells begin in a warm, moist, and unstable environment like other thunderstorms. The key difference is that supercells develop a *persistent* and *rotating* main updraft, the result of surrounding winds that veer from south to west with height and increase in speed. Supercells are most common east of the Rocky Mountains during spring and summer. However, they can occur at a variety of locations during different seasons when warm, moist air and the proper environmental wind conditions are associated with a weather system.

Supercells almost always produce severe weather, and an estimated 40% of them produce tornadoes.

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References

- Atlas, D., Editor, 1990: *Radar in Meteorology*. American Meteorological Society, Boston, 806 pp.
- Brown, R.A., 1992: Severe thunderstorms (meteorology). *Encyclopedia of Physical Science and Technology*, 2nd edition, 15, Academic Press, 107-125.
- Davies, J.M., 1990: Midget supercell spawns tornadoes. *Weatherwise*, Heldref Publications, Washington, D.C., 45, 260-261.
- Davies, J.M., 1993: Small tornadic supercells in the central plains. In *Preprints, 17th Conf. Severe Local Storms*, American Meteorological Society, Boston, 305-309.
- Doswell III, C.A., 1985: The operational meteorology of convective weather. Vol. II: Storm scale analysis. NOAA Technical Memorandum ERL ESG-15, 240 pp.
- Doswell III, C.A., and D.W. Burgess, 1993: Conceptual models of tornadoes and tornadic storms. In *The Tornado: Its Structure, Dynamics, Prediction and Hazards*, Geophysical Monograph 79, C. Church, D. Burgess, C. Doswell, & R. Davies-Jones, Editors, American Geophysical Union, Washington, D.C., 161-172.
- Doswell III, C.A., A.R. Moller, and R.W. Przybylinski, 1990: A unified set of conceptual models for variations on the supercell theme. In *Preprints, 16th Conf. Severe Local Storms*, American Meteorological Society, Boston, 40-45.
- Fujita, T.T., 1987: *U. S. Tornadoes: Part 1, 70-Year Statistics*, University of Chicago Press, SMRP Research Paper #228, 122 pp.
- Grazulis, T.P., 1993: *Significant Tornadoes 1680-1991*. Environmental Films, St. Johnsbury, VT, 1326 pp.
- Kessler, E.W., Editor, 1986: Thunderstorm Morphology and Dynamics. Vol. 2 of *Thunderstorms: A Social, Scientific, and Technological Documentary*, 2nd edition, University of Oklahoma Press, 411 pp.
- Moller, A.R., and C.A. Doswell III, 1988: Advanced Meteorologist/Spotter Training Slide Series. NOAA, National Weather Service, Warning and Forecast Branch, Silver Spring, MD, slide presentation and 44-page commentary.
- National Weather Service, 1992: A summary of natural hazard deaths for 1990 in the United States. Brochure, Silver Spring, MD, 9 pp.
- Przybylinski, R.W., J.T. Snow, E.M. Agee, and J.T. Curran, 1993: The use of volumetric radar data to identify supercells: A case study of June 2, 1990. In *The Tornado: Its Structure, Dynamics, Prediction and Hazards*, Geophysical Monograph 79, C. Church, D. Burgess, C. Doswell, & R. Davies-Jones, Editors, American Geophysical Union, Washington, D.C., 241-250.
- Ray, P.S., 1986: *Mesoscale Meteorology and Forecasting*. American Meteorological Society, Boston, 793 pp.
- Rust, W.E., W.L. Taylor, D.R. MacGorman, and R.T. Arnold, 1981: Research on electrical properties of severe thunderstorms in the Great Plains. *Bulletin of the American Meteorological Society*, 62, 1286-1293.
- Vavrek, J., R.L. Holle, and J. Allsopp, 1993a: Flash to bang. *The Earth Scientist*, National Earth Science Teachers Association, 10, 3-8.
- , —, and —, 1993b: Flash to bang. *Spectrum*, Illinois Science Teachers Association, 19, 21-26.
- , —, and —, 1994: Flash to bang. Reading 10 in *Project Earth Science: Meteorology*, P.S. Smith and B.A. Ford, Editors, National Earth Science Teachers Association, Arlington, VA, 210-219.