ADVANCED SPOTTERS' FIELD GUIDE

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

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Cover Photo - Alan Moller

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I. INTRODUCTION

The Spotter's Role

The National Weather Service (NWS) has a number of devices for detecting severe thunderstorms. Included in these are radar, satellite, and lightning detection networks. However, the most important tool for observing thunderstorms is the trained eye of the storm spotter. While radar is used quite often in severe storm warnings, conventional weather radar will only indicate areas and intensities of precipitation. It does not give any indication of cloud formations or wind fields associated with a storm. Doppler radar, which is being introduced across the country, will give some indication of air motions inside a storm. Doppler radar, though, will not give these indications down to ground level. It is impossible for any radar to detect every severe weather event in its coverage area, and radar occasionally suggests severe weather when, in fact, none is present.

Satellite and lightning detection networks provide general thunderstorm locations and are extremely valuable in data-sparse regions (such as over mountainous terrain or over bodies of water). They help to identify persistent thunderstorm areas and can be of aid in flash flood forecasting. These systems provide little in the way of quantitative real-time information, though, and are not especially helpful during times of fast-breaking severe weather.

As a trained spotter, you perform an invaluable service for the NWS. Your real-time observations of tornadoes, hail, wind, and significant cloud formations provide a truly reliable information base for severe weather detection and verification. By providing observations, you are assisting NWS staff members in their warning decisions and enabling the NWS to fulfill its mission of protecting life and property. You are helping to provide the citizens of your community with potentially life-saving information.

Objectives of this Handbook

During the past several years, researchers have uncovered a tremendous amount of information regarding severe thunderstorm structure and behavior. New theories regarding thunderstorm formation and tornado development have been presented. Storm-intercept teams have correlated these theories with observed visual features. Our current understanding of the thunderstorm is markedly more complete than it was just ten years ago.

With this handbook and the Advanced Spotter Training Slide Set which was released a few years ago, the time has come to pass this new understanding on to you, the spotter. Only by providing fresh training material can the NWS expect to maintain what has become a very important group of observers.

Prerequisites for Using this Guide

The information contained in this guide is not for the novice spotter. It is recommended that spotters go through two or more basic spotter training sessions and have some experience at actual storm spotting before attempting the intermediate/advanced training material. Spotters should be comfortable with the basic concepts of storm structure and storm spotting. Obviously, spotters should have a desire to learn the latest concepts of tornado and severe thunderstorm behavior.

II. REPORTING PROCEDURES

Primary and Secondary Contacts

It is essential that any spotter network have a clear set of procedures for reporting severe weather and other observations. All networks should have a designated methodology for relaying reports from the field to the local NWS office. There should be a primary contact for activation and operation of the spotter network. It is also suggested that a secondary contact be established for those occasions when widespread severe weather is occurring or when the primary contact is not available.

Amateur radio operators comprise the backbone of many spotter networks. Most amateur radio networks include an operator at the NWS office for quick relay of reports and direction of spotters in the field to "hot spots." This has proven to be an effective, efficient method of relaying severe weather observations. Other operators may be deployed at television or radio stations in the NWS office's county warning area.

Law enforcement and fire department personnel also serve as spotter networks in many areas. Many of these groups report to a dispatcher who, in turn, relays reports to the NWS. These spotter networks should establish a secondary contact (such as the dispatcher of another city/county agency) for those times when primary communications are impeded.

The dispatchers should also receive at least basic spotter training. Although they are not actually observing the storms in the field, dispatchers serve as a critical link in the severe weather information chain. If they are familiar with thunderstorm and spotting terminology, dispatchers are able to screen out less important observations and quickly relay significant reports to the local NWS office.

In remote or sparsely populated areas, private citizens may have to serve as spotters. While these groups may not be as well organized as the amateur radio or law enforcement-based groups, there should still be established reporting procedures. Local law enforcement or emergency management offices are candidates for contacts in these situations.

Spotter Coordination

Spotting is not a one-person job. It is difficult, if not impossible, for one spotter to accurately observe all aspects of a thunderstorm. Rather, it is necessary for spotters and spotter groups to coordinate and share information (with the NWS and with each other) to obtain the best possible assessment of the storm.

Spotters with two-way radio communications should talk not only with their dispatch/control personnel but with other spotters in the area. Positioning spotter teams at several strategic locations around a storm, with active communication between the spotters, should enable a great deal of information concerning the thunderstorm to be relayed to the local NWS office.

If two or more spotter groups are working in the same area (i.e., an amateur radio group and a law enforcement group), then these groups should share information regarding their observations. The NWS should also attempt to coordinate between spotter groups. As a storm moves from one spotter group's area to another, the downstream spotter group should be notified well in advance to allow time for their activation and deployment.

Reporting Criteria

There are certain criteria for reporting severe weather. Recall that a thunderstorm is defined as severe if it produces a tornado, hail 3/4 inch in diameter or larger, and/or wind gusts 58 miles an hour or higher. It would be desirable to report events associated with a thunderstorm before they reach these severe levels. Use the following guidelines for reporting weather events.

Report hail occurrences when the hailstones have a diameter of 1/2 inch, and report wind gusts when their speed reaches 50 miles an hour. See tables 1 and 2 for estimations of hail size and wind speed. Obviously, tornadoes and funnel clouds should be reported. A funnel cloud is defined as a violently rotating column of air which is not in contact with the ground. It is usually marked by a funnel-shaped cloud extending downward from the cloud base (hence its name). If the violently rotating air column reaches the ground, it is called a tornado. An important point to note is that the visible funnel DOES NOT have to extend to the ground for a tornado to be present. Instead, look for a rotating cloud of dust and debris underneath a funnel cloud as evidence that the tornado's circulation has reached the ground.

Hail Size Estimates

Pea	0.25	Golfball	1.75
Penny	0.75	Tennis Ball	2.50
Quarter	1.00	Baseball	2.75
Half Dollar	1.25	Grapefruit	4.00

Table 1: Hail Size Estimations.

Wind Speed Estimates

Speed (MPH)	Effects
25-31	Large branches in motion; whistling in telephone wires
32-38	Whole trees in motion
39-54	Twigs break off of trees; wind impedes walking
55-72	Damage to chimneys and TV antennas; pushes over shallow rooted trees
73-112	Peels surface off roofs; windows broken; trailer houses overturned
113+	Roofs torn off houses; weak buildings and trailer houses destroyed; large trees uprooted

Table 2: Wind Speed Estimations.

Flash flooding should be reported, but the reporting criteria are not as well defined as with severe weather events. A flash flood is defined as a rapid rise in water usually during or after a period of heavy rain. Variations in soil type, terrain, and urbanization result in a wide variation in the amount of runoff which will occur during and after a given amount of rain. Consult your local NWS office regarding flash flood reporting procedures in your area.

When making a report, you (or your dispatcher/control person) should include the following information:

(1) WHO you are, and the name of your spotter group.

(2) WHERE the event is occurring. Use reports from other nearby spotters to triangulate and pinpoint the event's location.

(3) WHAT you have seen (the severe weather event).

(4) MOVEMENT of the event. When estimating movement, don't use the motion of small cloud elements for estimation. Instead, observe the storm as a whole for estimates of motion.

III. SAFETY TIPS

Safety should be first and foremost on the mind of a spotter. Remember, the NWS values your safety more than we do your observations. It is essential that spotters proceed into the field armed not only with knowledge of the storms but also with an understanding of the dangers posed by thunderstorms.

When spotting, travel in pairs if at all possible. When moving, this will allow the driver to remain focused on the chore of driving while the passenger keeps an eye on the sky and handles any communication with the dispatcher. When stopped, two sets of eyes are available for observation.

Keep aware of the local environment at all times. When in the vicinity of a thunderstorm, keep a 2-mile "buffer zone" between you and the storm. Frequently check the sky overhead and behind to ensure no unexpected events (such as a new tornado) are developing. Always have an escape route available, in case threatening weather approaches or if you get within the 2-mile "buffer zone."

Lightning is the number one killer among weather phenomena. During a typical year, lightning kills more people than hurricanes, tornadoes, and winter storms combined. The two main threats posed by lightning are the intense heat of the lightning stroke (about 15,000 degrees Celsius) and the extreme current associated with the stroke, estimated at 30,000 amperes (less than 1 ampere can be fatal).

Lightning is also the biggest weather hazard facing the spotter. When in the field, the spotter will usually be in a preferred lightning strike area (in the open, on a hilltop, etc.). Whenever possible, remain in your spotting vehicle to minimize the chance of being struck by lightning. If you must leave your vehicle, crouch as low as possible to make yourself a less-favorable target.

Hail is usually not a direct threat to life, but hailstorms are the costliest weather element to affect the United States. Each year, hailstorms cause over $1 billion in damage primarily to crops, livestock, and roofs. Giant hailstones (2 inches or more in diameter) can reach speeds of 100 miles an hour as they fall to earth. If such a stone strikes someone, the results can be fatal. There have been only two documented hail-related deaths in the United States, but a hailstorm in China killed over 100 people in 1976. A vehicle will usually offer adequate protection from moderate-sized hailstones. Hail larger than golfball size may damage windshields, so avoid large hailshafts if at all possible.

Downbursts are underrated thunderstorm threats. A downburst is defined as a strong downdraft with an outrush of damaging winds on or near the earth's surface. Downbursts are responsible for the "wind shear" which has caused a number of airliner accidents in the 1970's and early 1980's. When people experience property damage from a downburst, they often do not believe that "just wind" could have caused the damage, and they assume that they were struck by a tornado. In fact, the strongest downbursts have wind gusts to near 130 miles an hour and are capable of the same damage as a medium-sized tornado.

Downbursts are classified based on their size. If the swath of damaging winds is 2.5 miles or greater, it is called a **macroburst**. If the swath is less than 2.5 miles across, it is called a **microburst**. In general, macrobursts are long-term, large-scale events, while microbursts are intense, quick-hitting phenomena. Microbursts are subdivided as **wet** or **dry** microbursts, depending on how much rain falls with the microburst. If very heavy rain falls with the microburst, it is called a **wet microburst**, while a **dry microburst** has little or no rain reaching the ground. Chapter VIII discusses downbursts in more detail and outlines some spotting tips regarding downbursts.

Flash floods are another example of an underrated thunderstorm threat. Over the past several years, more people have been killed in flash floods than in tornadoes. Two factors are responsible for this. First, we have urbanized. Where rain water used to have open fields in which to run off, it now has highway intersections, basements, streets, etc. Second, the public as a whole is apathetic about flash flooding. We simply do not treat flash flooding with the respect it deserves. Many of the recent deaths associated with flash flooding have occurred because people attempted to drive their vehicles across a flooded low-water crossing and were swept away by the floodwaters. Less than two feet of moving water is needed for a vehicle to be swept away.

When spotting in a flash flood situation, follow these common sense safety tips. Remember that flash flooding is most dangerous at night when the effects of flash flooding are difficult to see. Since most flash floods occur at night, this problem is compounded. Avoid low water crossings and don't drive into areas where water covers the road. If you are caught in a flash flood, abandon your vehicle and quickly get to higher ground.

Last but not least is the tornado. Again, a **tornado** is defined as a violently rotating column of air in contact with the ground and pendant from a thunderstorm (whether or not a condensation funnel is visible to the ground). If the violently rotating column of air has not touched the ground, it is called a **funnel cloud**. We will discuss the tornado in more detail in chapter IX.

If a tornado is approaching your location, drive away from the tornado IF you are in open country, IF the location and motion of the tornado are known, and IF you are familiar with the local road network. If you are in an urban area and escape is not possible for some reason, abandon your vehicle and get into a reinforced building. If a reinforced building is not available, get into a culvert, ditch, or other low spot in the ground (that is not flooded).

Spotting at night is obviously more difficult than spotting during the day. There are only a few allies available to help you when night spotting. If possible, use the light from lightning flashes to illuminate the important parts of the storm. Quite often, though, lightning strokes will be very brief and will illuminate different parts of the storm from different angles. This will make it even more difficult to accurately report what is occurring. If you are in large hail, the most dangerous part of the storm is near you and will probably move overhead within a few minutes. If you hear a loud roaring sound, then a tornado may be close to your location. Use this tip with caution. Not all tornadoes have a loud roar, and some non-tornadic winds may also possess a loud roar. Finally, if you think there is a tornado not far from your location (i.e., within spotting range), search along the horizon for bright flashes of light as the tornado destroys power lines and transformers.

IV. THE THUNDERSTORM

We must obtain a basic understanding of the thunderstorm before we can hope to understand tornadoes, hail, and other phenomena which are produced by the thunderstorm. Sometimes it is convenient to think of a thunderstorm as a solid object floating in the sky. Actually, a thunderstorm should be thought of as a process that takes heat and moisture near the earth's surface and transports it to the upper levels of the atmosphere. The by-products of this process are the clouds, precipitation, and wind that we associate with the thunderstorm.

At any given moment, there are roughly 2,000 thunderstorms in progress around the world. Most of these storms are beneficial, bringing needed rainfall to farmlands and reservoirs. Only a small fraction (less than 1 percent) of these storms is classified as severe, producing large hail 3/4 inch in diameter or larger and/or strong downburst wind gusts of 58 miles an hour (50 knots) or greater. A small fraction of the severe storms produce tornadoes. Thus, although any thunderstorm is theoretically capable of producing severe weather, only a very few storms will actually produce large hail, severe downburst winds, or tornadoes.

In the United States, the Florida Peninsula and the southeast plains of Colorado have the highest thunderstorm frequency. Relatively small thunderstorms occur about once a year in Alaska and 2-3 times a year in the Pacific Northwest. Although the greatest severe weather threat in the United States extends from Texas to southern Minnesota, it is important to note that **no place** in the United States is **completely** immune to the threats of severe weather.

Atmospheric Conditions for Thunderstorm Development

All thunderstorms, whether or not they become severe, must have three conditions present in order to form. The first necessary condition is moisture in the lower to mid levels of the atmosphere. As air rises in a thunderstorm updraft, moisture condenses into small water drops which form clouds (and eventually precipitation). When the moisture condenses, heat is released into the air, making it warmer and less dense than its surroundings. The added heat allows the air in the updraft to continue rising.

The second necessary condition is **instability**. If the airmass is unstable, air which is pushed upward by some force will continue upward. An unstable airmass usually contains relatively warm (usually moist) air near the earth's surface and relatively cold (usually dry) air in the mid and upper levels of the atmosphere. As the low-level air rises in an updraft, it becomes less dense than the surrounding air and continues to rise. This process is often augmented by added heat due to condensation as discussed above. The air will continue to move upward until it becomes colder and more dense than its surroundings.

The third necessary condition is a source of lift. Lift is a mechanism for starting an updraft in a moist, unstable airmass. The lifting source can take on several forms. The most common source is called **differential heating**. As the sun heats the earth's surface, portions of the surface (and the air just above the surface) will warm more readily than nearby areas. These "warm pockets" are less dense than the surrounding air and will rise. If the air has sufficient moisture and is unstable, a thunderstorm may form.

The source of lift can also be mechanical in nature. Moist air flowing up the side of a mountain may reach a point where it is less dense than its environment, and thunderstorms may develop. This is common on the eastern slopes of the Rocky Mountains during the summer. Advancing cold fronts, warm fronts, outflow boundaries, drylines, and sea breeze fronts also act as triggers by lifting moist, low-level air to the point where the low-level air is warmer and less dense than its environment at which time thunderstorms can form.

The Thunderstorm Life Cycle

All thunderstorms, whether or not they become severe, progress through a life cycle which may be divided into three main stages. The developing stage, called the cumulus or towering cumulus stage, is characterized by updraft (figure 1). As the updraft develops, precipitation is produced in the upper portions of the storm. As the precipitation begins to fall out of the storm, a downdraft is initiated. At this time, the storm enters its mature stage (figure 2). The mature stage is marked by a co-existence of updraft and downdraft within the storm. When the downdraft and rain-cooled air reach the ground, the rain-cooled air spreads out along the ground and forms the **gust front**. Usually the winds associated with the gust front are not severe, but in extreme cases, a downburst can develop and produce severe wind gusts.

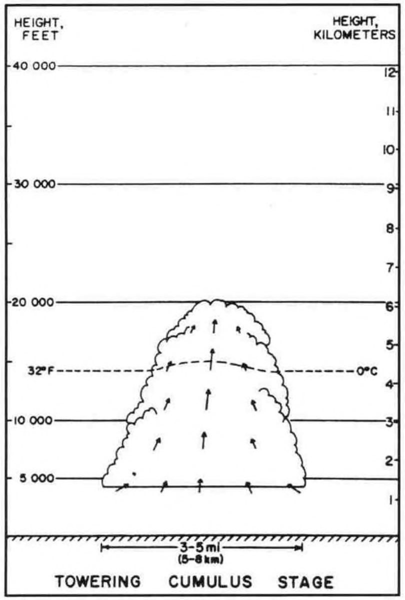

Figure 1: Towering cumulus stage of the thunderstorm. At this time, all air is moving upward in the developing storm.

Eventually, a large amount of precipitation is produced and the storm becomes dominated by downdraft. At the ground, the gust front moves out a long distance from the storm and cuts off the storm's inflow. This begins the dissipating stage of the thunderstorm (figure 3). Even though this thunderstorm has dissipated, its gust front may trigger new thunderstorms as it lifts warm, moist, unstable air.

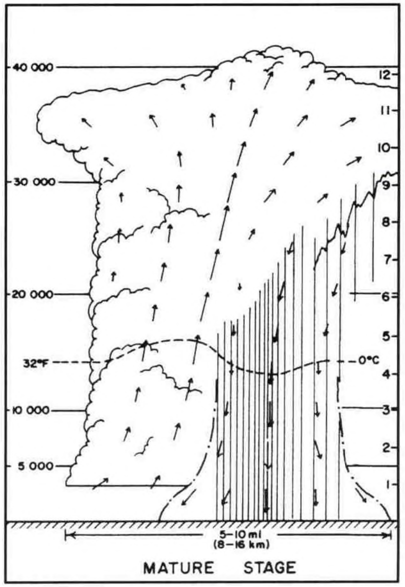

Figure 2: Mature stage of the thunderstorm. Updraft and downdraft are coexisting in the storm at this time.

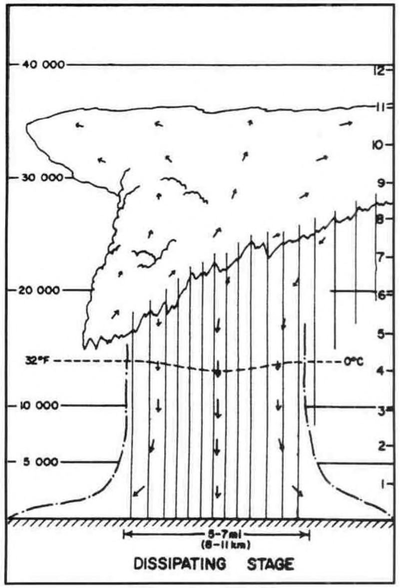

Figure 3: Dissipating stage of the thunderstorm. Updraft has weakened and the storm is dominated by downdraft.

Convective Variables

The three ingredients listed above are necessary for the development of thunderstorms. Recent research has found that if the environment (wind, moisture, or instability) of a storm is changed, then the type of storm (multicell, supercell, etc.) which is favored to exist may change as well.

The amount of **vertical wind shear** in the storm's environment is critical in determining what type of storm will form. Vertical wind shear is defined as a change in wind direction or speed with height. If the amount of vertical wind shear is low (little change in wind speed or direction), then multicellular storms with short-lived updrafts will be favored. Low values of vertical wind shear result in weak inflow to a storm. Because the inflow is weak, the outflow from the rainy downdraft area will push the gust front out away from the storm. This, in turn, will cut off the storm's source of warm, moist air, resulting in a storm with short-lived updrafts. Precipitation which is produced will fall through the storm's updraft and contribute to the updraft being short-lived. Figure 4 depicts a storm which developed in a low-shear environment.

As the vertical wind shear increases, storms with longer lived updrafts will be favored. Stronger vertical wind shear results in stronger inflow to the storm. The gust front will be "held" close to the storm, and the storm will have access to the source of warm, moist air for a much longer time. As a result, the storm's updraft will tend to last longer when the environment has strong vertical wind shear. Precipitation will tend to fall downwind from the updraft rather than through the updraft. This enables the updraft to continue for relatively long periods of time. Figure 5 shows a storm which developed in a high-shear environment.

Closely related to the concept of vertical wind shear is the **veering** of the wind with height in the lowest mile or so of the atmosphere. Veering is defined as a clockwise turning of the wind direction as we move up through the atmosphere. It is possible to make a rough check of veering winds while spotting. If there are two layers of clouds in the lower levels of the atmosphere, look closely at the directions in which the cloud layers are moving. If the direction turns clockwise between the lower and upper layers, then veering is present.

Computer simulations and observational studies have suggested that veering of the low-level wind is instrumental in the production of storm rotation. If the wind speed is sufficiently strong (usually 30 miles an hour or greater) and veering of the wind with height is present, then horizontally-oriented "rolls" may develop in the lower levels of the atmosphere. These horizontal "rolls" may then be tilted into a vertically-oriented rotation by a storm's updraft. The updraft can also "stretch" the vertical rotation and increase the rate of rotation. Once this vertical rotation has been established, a mesocyclone (see chapter V) can develop which may produce a tornado or significant severe weather.

Figure 4: Thunderstorm in a low-shear environment. Winds were below 40 mph throughout the depth of this storm. Photo - Alan Moller.

Figure 5: Thunderstorm in a high-shear environment. Wind speed changed 130 mph between the bottom and top of this storm, producing this extreme tilt. Photo - Alan Moller.

Variations in **moisture** or **instability** can also have an effect on thunderstorms. If the amount of moisture in the atmosphere is low (as might be found on the High Plains), the storms will tend to have high cloud bases. Small amounts of precipitation will fall from the storms, but they will typically have strong downdrafts. If moisture levels in the atmosphere are high (as might be found in the Southeast), then storms will have low cloud bases. Copious amounts of precipitation will reach the ground usually accompanied by weak downdrafts. A rule of thumb to keep in mind is: the higher the cloud base, the better the chance for dry microbursts. The lower the cloud base, the better the chance for flash flood-producing rainfall.

The amount of instability which is present plays an important role in the strength of a thunderstorm's updraft and downdraft. If the instability is low, then a storm's drafts will probably not be strong enough to produce severe weather. If the storm's environment has high instability, then the storm's drafts will be stronger, and the storm will have a better chance of producing severe weather.

Another important factor in the storm's environment, although not as critical as the above-mentioned factors, is the presence of a **mid-level capping inversion**. The mid-level capping inversion is a thin layer of warm air between the low-level moist air and the upper-level cold (usually dry) air. If the mid-level cap is weak or is not present, then storms will usually form early in the day before the sun's strong heating can produce high amounts of instability. A number of storms may form, but the storms will generally be weak and poorly organized. If the mid-level cap is strong, then storms may not form at all. The very warm mid-level temperatures will literally act as a lid, preventing updrafts from growing above the cap.

A mid-level cap of moderate strength is preferred for the development of severe thunderstorms. A moderate cap will prevent weak storms from forming, thus "saving up" the atmosphere's instability. When storms do form, usually in the mid to late afternoon, only the strongest few updrafts will be able to break through the cap and continue to develop. These few storms can take advantage of the high instability which is present, with little competition from nearby storms, and possibly develop into severe thunderstorms.

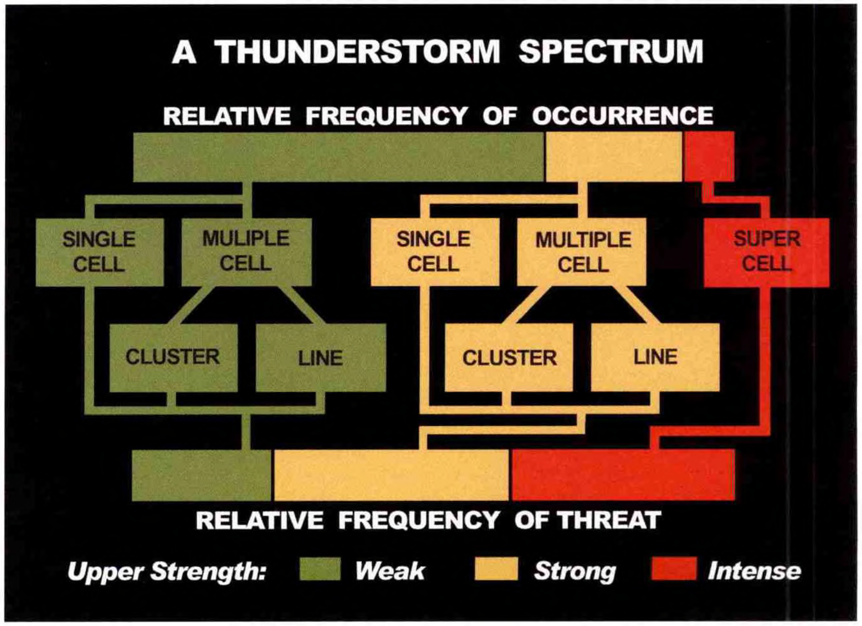

Figure 6: The thunderstorm spectrum. The four main storm categories are listed in the boxes. The bar graphs indicate the frequency and threat with storms of various updraft strength.

V. THUNDERSTORM TYPES

In earlier spotter training material, thunderstorms were classified based on their destructive potential (non-severe, severe, and tornadic). A better way to classify storms is to base the categories on their actual physical characteristics. There is actually a continuous spectrum of thunderstorm types, but there are four broad categories of storms that will be discussed: single cell storms, multicell cluster storms, multicell line storms, and supercell storms. The thunderstorm spectrum is shown in figure 6.

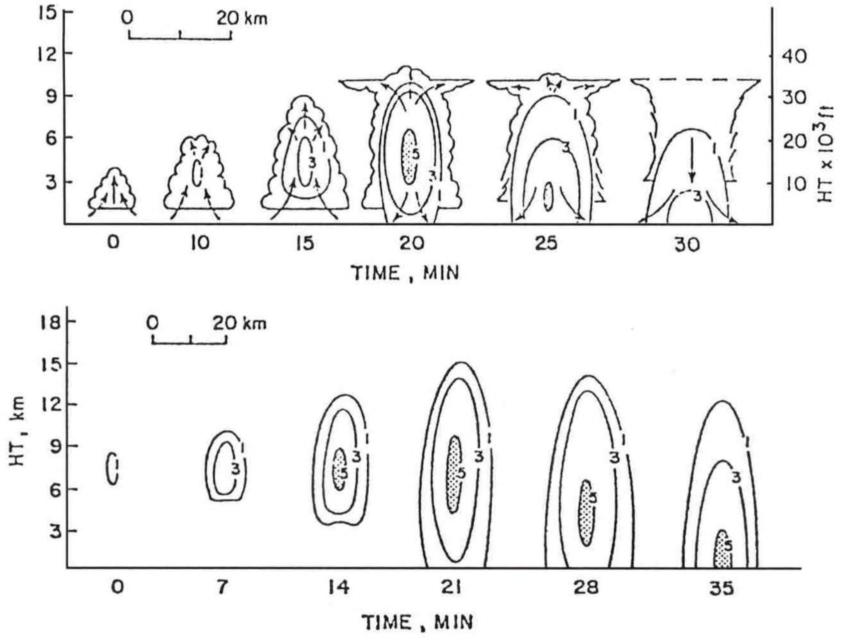

Figure 7: Cloud outlines and radar intensity of a single cell storm (top) and radar intensity of a "pulse" severe storm (bottom).

The Single Cell Storm

Single cell thunderstorms have lifetimes of 20-30 minutes. They usually are not strong enough to produce severe weather. A true single cell storm is actually quite rare. Even with separate appearing storms in weak vertical wind shear, the gust front of one cell often triggers the growth of another cell some distance away.

Although most single cell storms are non-severe, some single cell storms may produce brief severe weather events. These storms, called pulse severe storms, tend to form in more unstable environments than the non-severe single cell storm. Pulse severe storms have slightly stronger draft speeds and typically produce marginally severe hail and/or brief microbursts. Brief heavy rainfall and occasional weak tornadoes can also be expected (it should be remembered that **any** thunderstorm is theoretically capable of producing a tornado). Figure 7 illustrates the life cycle of a pulse severe storm. Because single cell storms are poorly organized, and because they seem to occur at random times and locations, it is difficult to forecast exactly when and where severe weather will occur.

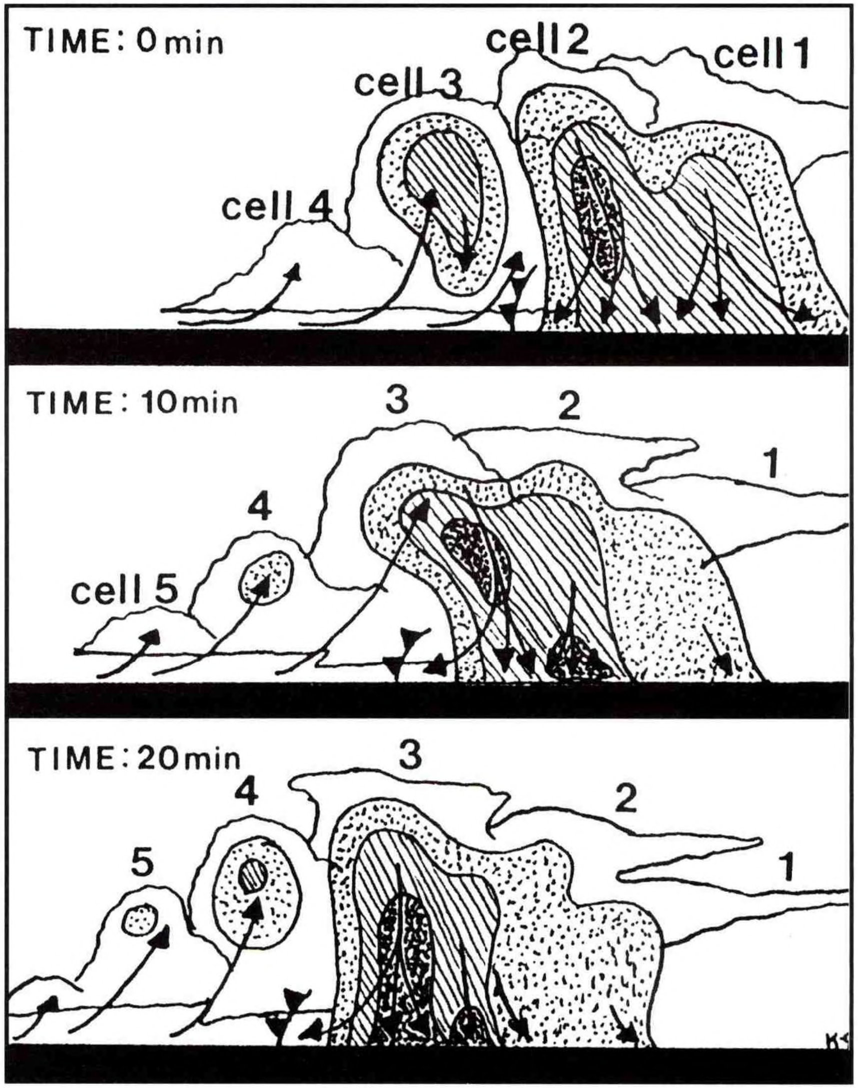

Figure 8: Propagation of a multicell cluster storm. Cloud outlines and radar echo intensities are shown.

The Multicell Cluster Storm

The multicell cluster is the most common type of thunderstorm. The multicell cluster consists of a group of cells, moving along as one unit, with each cell in a different phase of the thunderstorm life cycle. As the cluster moves along, each cell takes its turn as the dominant cell in the cluster. New cells tend to form at the upwind (usually western or southwestern) edge of the cluster. Mature cells are usually found at the center of the cluster with dissipating cells at the downwind (usually eastern or northeastern) edge of the cluster. See figures 8 and 9 for schematic diagrams of multicell cluster storms.

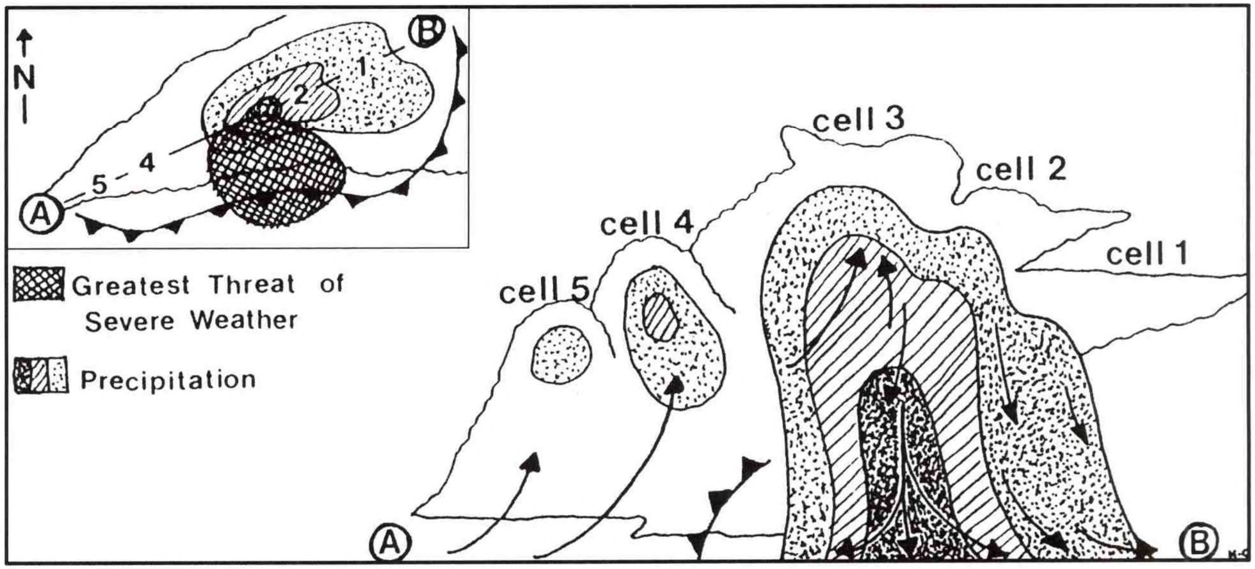

Figure 9: Schematic diagram of a multicell cluster storm. Cloud outlines, radar intensities, and the area of greatest severe weather probability are shown.

Although each cell in a multicell cluster lasts only about 20 minutes (as with a single cell storm), the multicell cluster itself may persist for several hours. Multicell clusters are usually more intense than single cell storms but are much weaker than supercell storms. Multicell cluster storms can produce heavy rainfall (especially if a number of cells mature over the same area), downbursts (with wind speeds up to about 80 miles an hour), moderate-sized hail (up to about golfball size), and occasional weak tornadoes. Severe weather will tend to occur where updrafts and downdrafts are close to each other (i.e., near the updraft-downdraft interface (UDI) associated with mature cells).

The Multicell Line Storm

The multicell line storm (or "squall line," as it is more commonly called) consists of a long line of storms with a continuous, well-developed gust front at the leading edge of the line. The line of storms can be solid, or there can be gaps and breaks in the line. Figure 10 shows a schematic diagram of a squall line. As the gust front moves forward, the cold outflow forces warm unstable air into the updraft. The main updraft is usually at the leading (eastern) edge of the storm, with the heaviest rain and largest hail just behind (to the west of) the updraft. Lighter rain, associated with older cells, often covers a large area behind the active leading edge of the squall line.

Squall lines can produce hail up to about golfball size, heavy rainfall, and weak tornadoes, but they are best known as prolific downburst producers. Occasionally, an extremely strong downburst will accelerate a portion of the squall line ahead of the rest of the line. This produces what is called a **bow echo** (figure 11). As figure 11 illustrates, bow echoes can develop with isolated cells as well as squall lines. Bow echoes are easily detected on radar but are difficult (or impossible) to observe visually. It is not your job to detect bow echoes, but you do need to know what you will be up against should you encounter a bow echo complex: namely, very strong downburst winds.

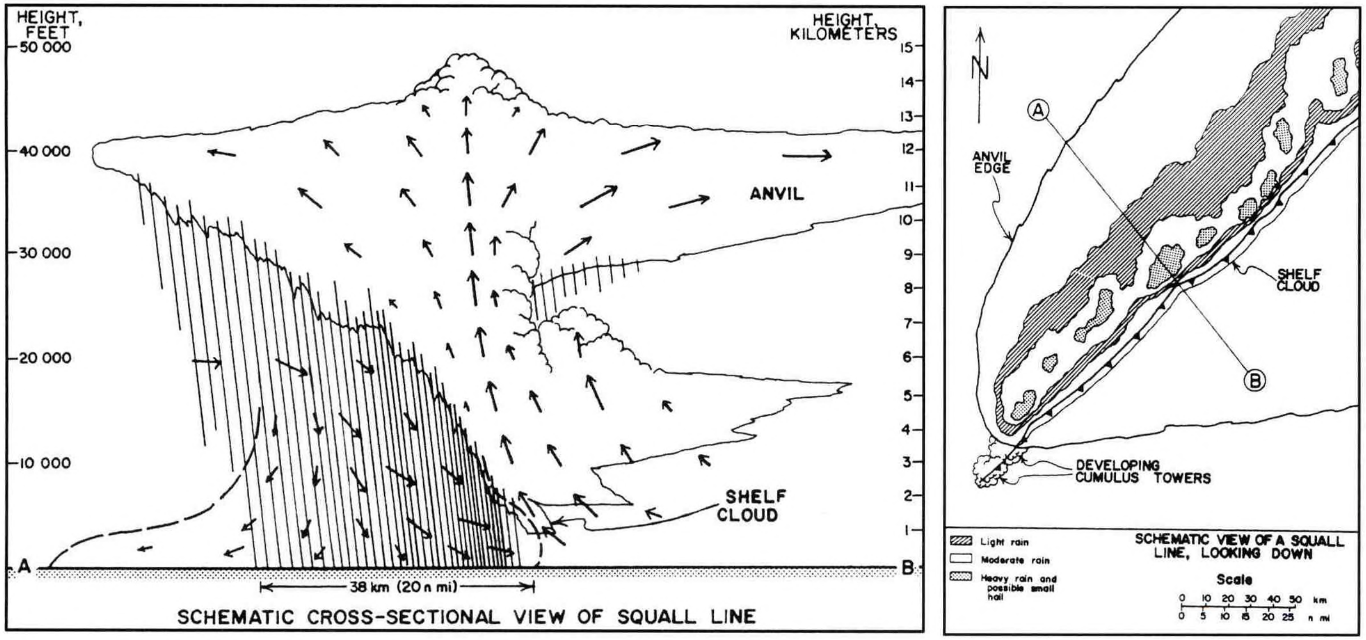

Figure 10: Schematic diagram of a squall line. Cloud outlines, radar intensities, and the area of greatest severe weather/ tornado threat are shown.

As with multicell cluster storms, squall lines usually produce severe weather near the UDI. Recall that this is near the leading (eastern) edge of the storm. If tornadoes are associated with a squall line, they will usually develop in cells that are just north of a break in the line or in the line's southernmost cell (sometimes called the "anchor cell"). Cells in these locations tend to behave more like supercells than typical squall line cells.

The Supercell Storm

The supercell is a highly organized thunderstorm. Although supercells are rare, they pose an inordinately high threat to life and property. Like the single cell storm, the supercell consists of one main updraft. However, the updraft in a supercell is extremely strong, reaching estimated speeds of 150-175 miles an hour. The main characteristic which sets the supercell apart from the other thunderstorms we have discussed is the element of rotation. The rotating updraft of a supercell, called a **mesocyclone**, helps the supercell to produce extreme severe weather events, such as giant hail (more than 2 inches in diameter), strong downbursts of 80 miles an hour or more, and strong to violent tornadoes.

Recall that the supercell environment is characterized by high instability, strong winds in the mid and upper atmosphere, and veering of the wind with height in the lowest mile or so. This environment is a contributing

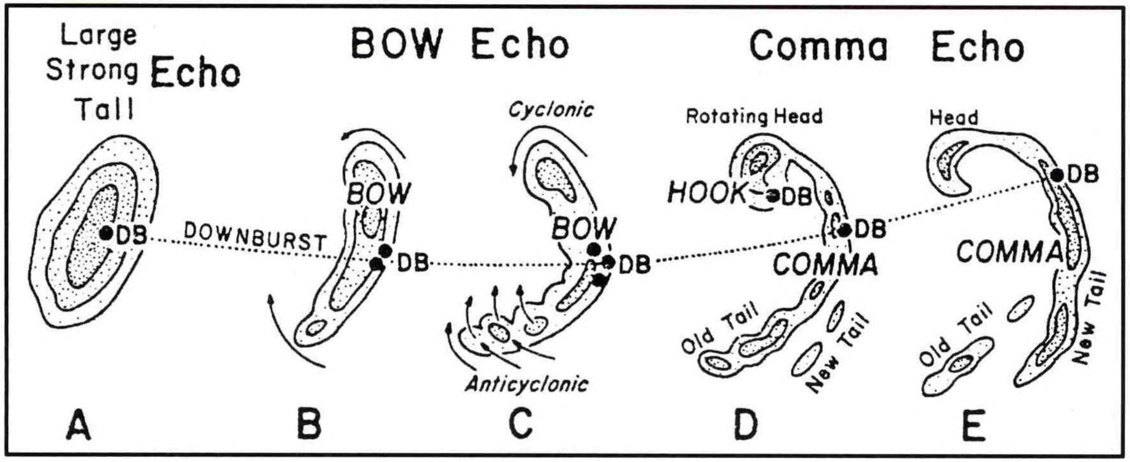

Figure 11: Schematic diagram of a bow echo. Strong downburst winds accelerate a portion of the storm, producing the bow or comma echo configurations shown.

factor to the supercell's organization. As precipitation is produced in the updraft, the strong upper level winds literally blow the precipitation downwind. Relatively little precipitation falls back down through the updraft, so the storm can survive for long periods of time with only minor variations in strength. As mentioned earlier, the veering winds with height assist the mesocyclone formation within the supercell.

The leading edge of a supercell's precipitation area is characterized by light rain. Heavier rain falls closer to the updraft with torrential rain and/or large hail immediately north and east of the main updraft. The area near the main updraft (typically towards the rear of the storm) is the preferred area of severe weather formation. Figures 12 and 13 show diagrams of a supercell storm.

In the next few sections, we will examine the visual aspects of the supercell (and other severe thunderstorms) in more detail. We will also discuss the tornado and some variations in the supercell model we presented above.

VI. VISUAL ASPECTS OF SEVERE THUNDERSTORMS

At first glance, it may seem difficult to tell a severe thunderstorm from a "garden variety" thunderstorm. There are, however, a number of visual clues which can be used to gain an idea of a thunderstorm's potential strength and organization, and the environment in which the storm is developing. Many of these visual clues are interrelated, but for discussion's sake, we will classify these clues as upper-level, mid-level, and low-level features of the storm which is being observed.

Upper-Level Features

Most of the upper-level clues are associated with the thunder-storm's **anvil**. Recall that the anvil is a flat cloud formation at the top of the storm (figure 14). Air (and cloud material) rising in the updraft reaches a point

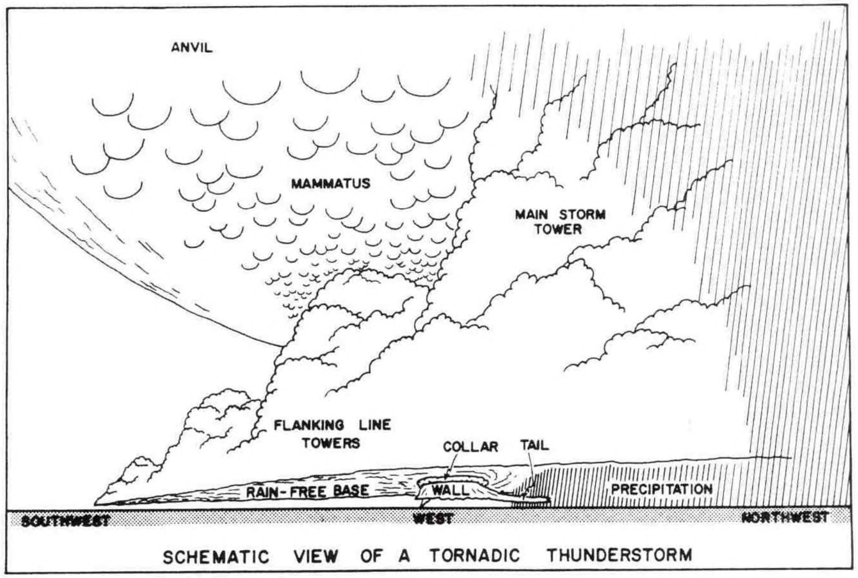

Figure 12: Side view of a supercell storm. View is to the northwest. Prominent features of the storm are indicated.

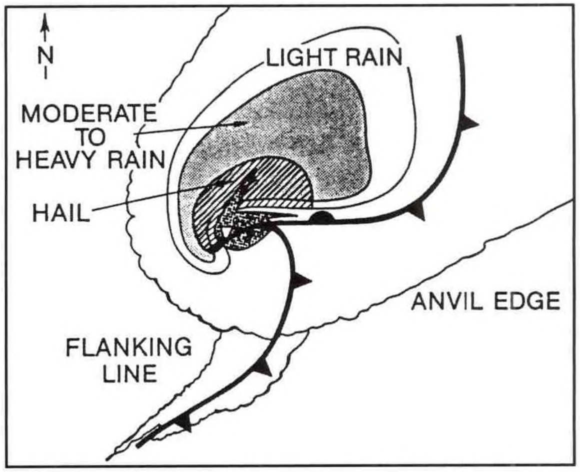

Figure 13: Overhead view of a supercell storm. The precipitation area, gust front, and cloud features are shown.

Figure 14: The overshooting top, thick anvil, vertical updraft tower, and "hard" texture to the updraft tower suggest storm severity.
Photo - Tim Marshall.

Figure 15: The glaciated anvil and the "soft" updraft tower (behind the towering cumulus in the foreground) suggest a lack of severity.
Photo - National Severe Storms Laboratory (NSSL).

where it begins to slow down. This level is called the **equilibrium level**. The air (and cloud material) rapidly slows its upward motion after passing the equilibrium level. As the air (and cloud material) spreads out, the anvil is formed.

If the storm you are watching has a vigorous updraft, a small portion of the updraft air will rise higher than the surrounding anvil. This will form a "bubble" of cloud sticking up above the rest of the anvil. The bubble is called an **overshooting top** (again, see figure 14). Most thunderstorms will have small, short-lived overshooting tops. However, if you observe a storm with a large, dome-like overshooting top that lasts for a fairly long time (more than 10 minutes), chances are good that the storm's updraft is strong enough and persistent enough to produce severe weather.

The anvil itself will also provide clues to the storm's strength and persistence. If the anvil is thick, smooth-edged, and cumuliform (puffy, like the lower part of the storm), then the storm probably has a strong updraft and is a good candidate to produce severe weather. This is also shown in figure 14. If the anvil is thin, fuzzy, and glaciated (wispy, similar to cirrus clouds), then the updraft is probably not as strong, and the storm is less likely to produce severe weather (figure 15). If the anvil is large and seems to be streaming away from the storm in one particular direction, then there are probably strong upper-level winds in the storm's environment. The storm will be well ventilated, meaning precipitation will probably be blown downstream away from the updraft rather than fall through the updraft.

Mid-Level Features

Most of the mid-level cloud features are associated with the storm's main updraft tower. If the clouds in the main updraft area are sharply outlined with a distinct cauliflower appearance, then the clouds are probably associated with a strong updraft which may produce severe weather (figure 14). If they have a fuzzy, "mushy" appearance to them, then the updraft probably is not as strong as in figure 15. If the updraft tower itself is vertical (almost perfectly upright), then the storm probably has an updraft strong enough to resist the upper-level winds blowing against it (again, see figure 14). On the other hand, if the updraft leans downwind (usually northeast), then the updraft is weaker (figure 16).

Figure 16: Updraft strength vs. environmental wind speed. Compare the vertical severe storm at left to the tilted updraft of the towering cumulus at right. Photo - Howard Bluestein.

Figure 18: Striations are evident as the corkscrew-type markings on the side of this supercell updraft tower. View is to the west. Photo - Alan Moller.

Figure 17: Flanking line of a supercell. View is to the southeast. Photo - Charles Doswell III.

Figure 19: The rain-free base. This marks the primary area of updraft in the storm. View is to the northwest. Photo - Alan Moller.

Thunderstorms with good storm-scale organization typically have a series of smaller cloud towers to the south or southwest of the main storm tower. These smaller towers are called a **flanking line** and usually have a stair-step appearance as they build toward the main storm tower. This is shown in figure 17.

Some supercells, as their mesocyclones develop, will show signs of rotation in the updraft tower. You may see **striations** on the sides of the storm tower. Striations are streaks of cloud material that give the storm tower a "corkscrew" or "barber pole" appearance and strongly suggest rotation (figure 18). A **mid-level cloud band** also may be apparent. The mid-level cloud band is a ring of cloud material about halfway up the updraft tower encircling the tower like a ring around a planet. This is another sign of possible rotation within the storm.

As a storm increases in size and intensity, it will begin to dominate its local environment (within about 20 miles). If cumulus clouds and other storms 5-15 miles away from the storm of interest dissipate, it may be a sign that the storm of interest is taking control in the local area. Sinking motion on the edges of the storm may be suppressing any nearby storms. All of the instability and energy available locally may be focused into the storm of interest which could result in its continued development.

Low-Level Features

Some of the most critical cloud features for assessing thunderstorm severity and tornado potential are found at or below the level of the cloud base. While there is a lot of information to be discerned in these low-level cloud features, most of the confusion (and frustration) associated with storm spotting stems from attempting to interpret these similar appearing but meteorologically distinct cloud formations.

Perhaps the easiest low-level feature to identify is the **rain-free base** (figure 19). As its name suggests, this is an area of smooth, flat cloud base beneath the main storm tower from which little or no precipitation falls. The rain-free base is usually just to the rear (generally south or southwest) of the precipitation area. The rain-free base marks the main area of inflow where warm, moist air at low levels enters the storm. Some have called the rain-free base the "intake area" of the storm.

We earlier discussed the domination by a storm of its local environment. Besides suppressing any nearby storms or clouds, this local domination can also show itself through the presence of **inflow bands**, ragged bands of low cumulus clouds which extend from the main storm tower to the southeast or south. The presence of inflow bands suggests that the storm is gathering low-level air from several miles away. The inflow bands may also have a spiralling nature to them, suggesting the presence of a mesocyclone.

The **beaver's tail** is another significant type of cloud band. The beaver's tail is a smooth, flat cloud band which extends from the eastern edge of the rain-free base to the east or northeast as shown in figure 20. It usually skirts around the southern edge of the precipitation area. The beaver's tail is usually seen with high-precipitation supercells (which will be discussed later) and suggests that rotation exists within the storm.

Lowerings of the rain-free base and "accessory clouds," such as shelf clouds and roll clouds, mark important areas of the storm. The next chapter will discuss wall clouds and other lowerings in more detail.

Figure 20: A beaver's tail is seen extending to the right of the main updraft tower. View is to the north. Photo - Alan Moller.

VII. WALL CLOUDS AND OTHER LOWERINGS

Wall Clouds

The **wall cloud** is defined as an isolated cloud lowering attached to the rain-free base. The wall cloud is usually to the rear (generally south or southwest) of the visible precipitation area. Sometimes, though, the wall cloud may be to the east or southeast of the precipitation area. This is usually the case with high-precipitation supercells where the precipitation has wrapped around the western edge of the updraft. Wall clouds are usually about two miles in diameter and mark the area of strongest updraft in the storm. See figure 21 for examples of wall clouds.

As the storm intensifies, the updraft draws in low-level air from several miles around. Some low-level air is pulled into the updraft from the rain area. This rain-cooled air is very humid; the moisture in the rain-cooled air quickly condenses (at a lower altitude than the rain-free base) to form the wall cloud. This process is shown in figure 22.

Shelf Clouds and Roll Clouds

Shelf clouds and **roll clouds** are examples of "accessory clouds" that you may see beneath the cloud base of a storm. Shelf clouds are long, wedge-shaped clouds associated with the gust front (figure 23). Roll clouds are tube-shaped clouds and are also found near the gust front (figure 24).

Shelf/roll clouds can develop anywhere an area of outflow is present. Shelf clouds typically form near the leading edge of a storm or squall line. A shelf cloud can form under the rain-free base, however, and take on the appearance of a wall cloud. A shelf cloud may also appear to the southwest of a wall cloud in association with a phenomena called the rear flank downdraft (which will be discussed later).

Figure 21: (a, b, & c) The wall cloud is an isolated lowering of the rain-free base. It marks an area of strong updraft. Photos - NWS, David Hoadley, Steve Tegtmeier.

Figure 22: Wall cloud formation (top). As cool, moist air is pulled from the rain area, the moisture quickly condenses to form the wall cloud (bottom). Photos - Alan Moller.

Shelf Clouds vs. Wall Clouds

Perhaps your biggest challenge as a spotter will be to discern between shelf clouds under the rain-free base and legitimate wall clouds. Remember that shelf clouds signify an area of downdraft and outflow while wall clouds indicate an area of updraft and inflow. If a shelf cloud is observed for several minutes, it will tend to move **away** from the precipitation area. A wall cloud, though, will tend to maintain its relative position with respect to the precipitation area. Shelf clouds tend to slope **downward** away from the precipitation while wall clouds tend to slope **upward** away from the precipitation area. Table 3 summarizes these differences.

Wall Clouds vs. Shelf Clouds

Wall Clouds:	**Shelf Clouds:**
Suggest inflow/updraft	Suggest downdraft/outflow
Maintain position with respect to rain	Move away from rain
Slope upward away from precip. area	Slope downward away from precip. area

Table 3: Characteristics of Wall Clouds vs. Shelf Clouds.

Only a few of the lowerings that will be seen when spotting will be legitimate wall clouds, and only a few of these wall clouds will actually produce tornadoes. Once a wall cloud has been positively identified, the next challenge will be to determine its tornado potential. There are four main characteristics usually observed with a tornadic wall cloud. First, the wall cloud will be **persistent**. It may change its shape, but it will be there for 10-20 minutes before the tornado appears. Second, the wall cloud will exhibit **PERSISTENT rotation**. Sometimes the rotation will be very visible and violent before the tornado develops. Third, strong surface winds will blow in toward the wall cloud from the east or southeast **(inflow)**.

Figure 23: Shelf cloud. The shelf cloud marks an area of thunderstorm outflow. Photo - Alan Moller.

Figure 24: Roll cloud. Similar to the shelf cloud, the roll cloud also marks an area of storm outflow. View is to the southwest. Photo - Gary Woodall.

Usually surface winds of 25-35 miles an hour are observed near tornadic wall clouds. Fourth, the wall cloud will exhibit evidence of **rapid vertical motion**. Small cloud elements in or near the wall cloud will quickly rise up into the rain-free base. Not all tornadic wall clouds will have these characteristics (and some tornadoes do not form from wall clouds), but these four characteristics are good rules of thumb to follow.

VIII. NON-TORNADIC SEVERE WEATHER PHENOMENA

Downbursts

Recall that a downburst is defined as a strong downdraft with an outrush of damaging winds on or near the ground. Downbursts are subdivided based on their size. If the swath of damaging winds is 2.5 miles or greater in diameter, then it is termed a **macroburst**. If the swath is less than 2.5 miles, it is called a **microburst**. In general, microbursts are quick-hitting events and are extremely dangerous to aviation. Microbursts are subclassified as **dry** or **wet** microbursts, depending on how much (or little) rain accompanies the microburst when it reaches the ground.

Figure 25 shows the life cycle of a microburst. The formative stage of a microburst occurs as the downdraft begins its descent from the cloud base (figure 26) . The microburst accelerates downward, reaching the ground a short time later. The highest wind speeds can be expected shortly after the microburst impacts the ground (figure 27). As the cold air of the microburst moves away from the center of the impact point, a "curl" will develop (figure 28). Winds in this "curl" will accelerate even more, resulting in even greater danger to aircraft in the area. After several minutes, the microburst dissipates, but other microbursts may follow a short while later.

While spotting microbursts may not seem as dramatic as spotting tornadoes, it is important to the NWS, the public, and the aviation interests that microbursts be identified and reported. Listed below are some visual clues for identifying microbursts.

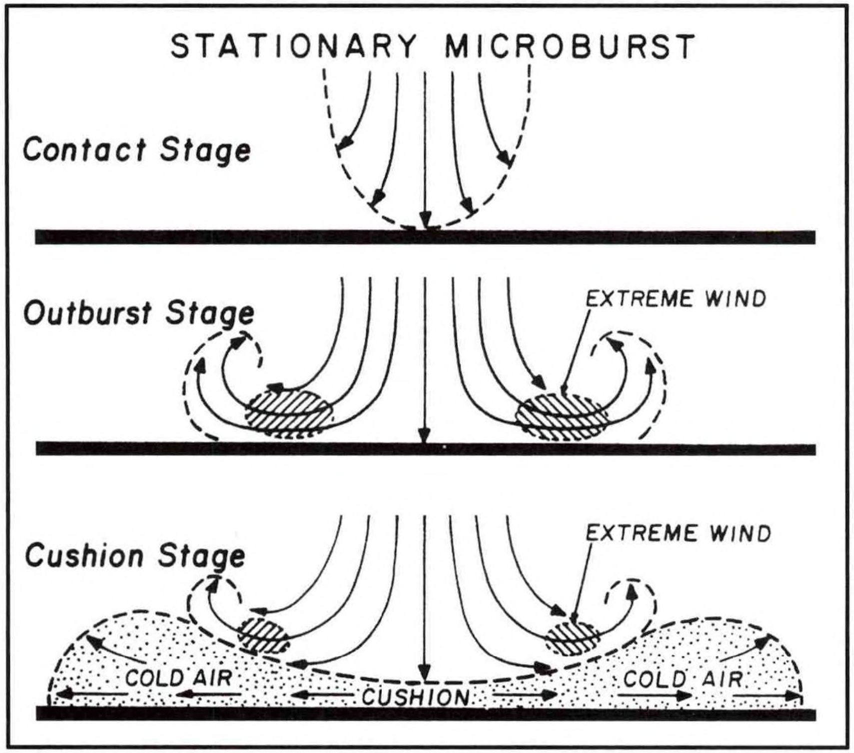

Figure 25: Life cycle of a microburst.

Patches of **virga** mark potential microburst formation areas. Virga is defined as precipitation which evaporates before reaching the ground. As the precipitation evaporates, it cools the air and starts a downdraft. If atmospheric conditions are right, the downdraft may accelerate and reach the ground as a microburst. Localized areas or rings of blowing dust raised from the ground usually mark the impact point of dry microbursts.

A small, intense, globular rain area, with an area of lighter rain in its wake, may mark a wet microburst. This is shown in figure 28. A **rain foot**, a marked outward distortion of the edge of a precipitation area, is also a visual indicator of a possible wet microburst (figure 29). As the microburst reaches the ground and moves away from its impact point, a plume of dust may be raised from the ground. This plume is called a **dust foot** and also marks a possible microburst (figure 30).

Flash Floods

Recall that a flash flood is defined as a rapid rise in water usually associated with heavy rains from a thunderstorm. For many years, flash floods were the leading cause of death and injury among weather phenomena. Although casualty rates from flash floods are decreasing, many people still unnecessarily fall victim to flash floods.

The atmospheric conditions which cause flash floods have been found to be somewhat different from those which produce severe thunderstorms. The typical flash flood environment has abundant moisture through a great depth of the atmosphere. Low values of vertical wind shear are usually present. Flash flooding commonly occurs at night, rather than in the late afternoon or evening. Flash flooding is typically produced by either large, slow-moving storms or by "train effect" storms. The "train effect" occurs when several storms sequentially mature and drop their rainfall over the same area. This can occur when multicell cluster or squall line storms are present.

There are three types of flooding which may occur due to excessive rainfall over an area in a short period of time. The main difference lies in the terrain on which the rain falls. The first type is the classic "wall of water" which occurs in canyons and mountainous areas. In this type of flooding, rainwater rapidly runs off and is funneled into deep canyons and gorges, where it quickly rushes downstream. The second type, called "ponding," is common in relatively flat areas. The rain-water collects in drainage ditches and other low-water crossings and is particularly a problem in rural areas. The third type is "urban flooding." Extensive concrete and pavement in urban areas results in a large amount of rainwater runoff which collects in street intersections, underpasses, and dips in roads.

As mentioned in chapter II, it is difficult to set spotting and reporting guidelines regarding flash flooding. Local differences in geography, soil type and character, and urbanization result in widely varying amounts of runoff for a given amount of rain. Consult your local NWS office for guidelines regarding flash flooding in your area. Of course, keep the safety rules outlined in chapter III in mind anytime flash flooding is a possibility.

Figure 26: Formative stage of a wet microburst. The downdraft (in the developing heavy rain area) is accelerating toward the ground. Photo - Bill Bunting.

Figure 28: Dissipating stage of a wet microburst. The curl is still evident on the edges of the microburst's impact area. Photo - Bill Bunting.

Figure 27: Impact stage of a wet microburst. This marks the most dangerous stage in the microburst's life. Photo - Bill Bunting.

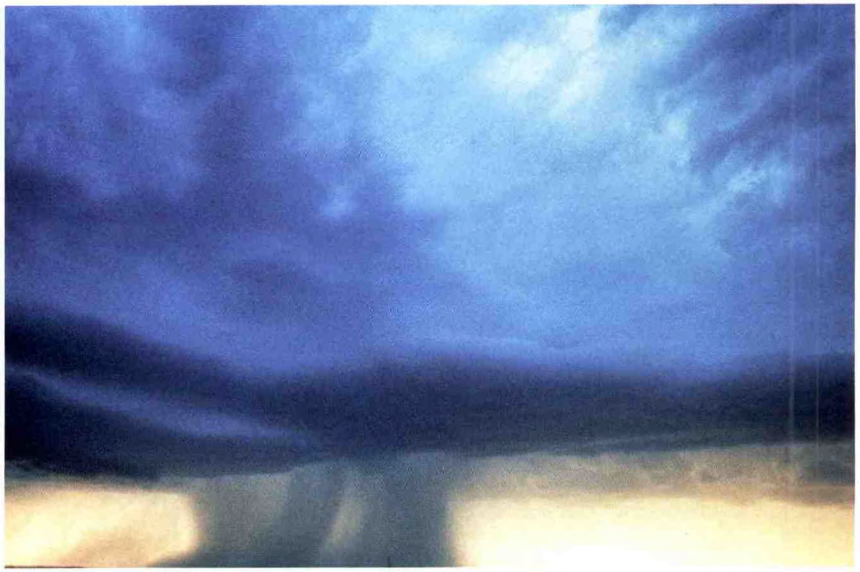

Figure 29: A rain foot, an outward deflection of the rain shaft, may also suggest a wet microburst. View is to the west. Photo - Charles Doswell III.

Figure 30: Similar to the rain foot, the dust foot indicates the presence of a microburst. Photo - Alan Moller.

IX. THE TORNADO

Life Cycle

Figure 31 illustrates the life cycle of a tornado. Although not all tornadoes form from mesocyclones, most of the larger and stronger tornadoes are spawned from supercell storms with mesocyclones. Recall that a supercell's environment usually contains strong, veering winds in the lowest mile or so of the atmosphere. These strong, veering winds produce horizontal vorticity ("rolls") in the lower few thousand feet of the atmosphere. The thunderstorm's updraft then tilts these horizontal "rolls" into vertically-oriented rotation and allows the mesocyclone to form. The tornado circulation develops at mid levels (about 20,000 feet) in the storm where the storm's updraft and mesocyclone are strongest. The circulation gradually builds down (and up) within the storm. At about the same time, a downdraft develops at mid levels near the back edge of the storm. This downdraft, called a **rear flank downdraft** (RFD) descends to the ground along with the tornado circulation. Rapidly lowering barometric pressure near the ground is believed to be the primary means of drawing the tornado circulation and RFD down toward the ground. The RFD may reveal itself as a "clear slot" or "bright slot" just to the rear (southwest) of the wall cloud. Sometimes, a small shelf cloud will form along this clear slot. Eventually, the tornado and RFD will reach the ground within a few minutes of each other (figure 31a).

After the tornado touches down, an ample inflow of warm, moist air continues into the tornado/mesocyclone. The RFD, though, will begin to wrap around the tornado/mesocyclone after the RFD impacts the ground. The RFD will actually cut off the inflow to the tornado as it wraps around the tornado/ mesocyclone. Wind damage may result from the RFD's gust front as it progresses around the mesocyclone (figure 31b).

When the RFD completely wraps around the tornado/mesocyclone, the inflow to the tornado/mesocyclone will be completely cut off. The tornado will gradually lose intensity. The condensation funnel will decrease in size, the tornado will tilt with height, and the tornado will eventually take on a contorted, rope-like appearance before it completely dissipates (figure 31c).

Tornado Variations

Not all tornadoes go through the life cycle outlined above. Some tornadoes proceed from the developing stage directly to the dissipating stage, with little time spent in the mature stage. As can be seen in the figures accompanying the above section, tornadoes take on quite different appearances as they develop, mature, and decay. Additional tornado examples are shown in figure 32.

Figure 33 illustrates a **multiple-vortex** tornado. As their name suggests, multiple-vortex tornadoes have two or more circulations (vortices) orbiting about each other or about a common center. The public often describes multiple-vortex tornadoes as "several tornadoes which join together to form one large tornado." Most of the deadly, destructive tornadoes the United States has experienced in the past (Oelwein, Iowa, 1968; Xenia, Ohio, 1974; Wichita Falls, Texas, 1979; Albion, Pennsylvania, 1985, to name a few) were multiple-vortex tornadoes. If you observe a multiple-vortex tornado, relay that fact to your dispatcher/controller, and stay clear!

Figure 31: (a) Funnel cloud extending toward ground from wall cloud.

(b) Mature tornado (note clear slot in front wall cloud.)

(c) Dissipating (rope) stage of tornado.
Photos - NSSL.

Figure 32: Tornado examples. (a) Thin tornado.

(b) Large violent tornado.

(c) Dust-tube tornado.
Photos - Tim Marshall, Institute for Disaster Research and George Kuykendall.

Figure 33: Multiple-vortex tornado. Photo - Howard Bluestein.

Tornado Classification

Dr. Theodore Fujita, a renowned severe weather researcher at the University of Chicago, developed a scheme for rating tornadoes based on their intensity. His scale, called the **F scale**, gives tornadoes a numerical rating from F0 to F5. F0 and F1 tornadoes are considered "weak" tornadoes, F2 and F3 tornadoes are classified as "strong" tornadoes, and F4 and F5 tornadoes are categorized as "violent" tornadoes. Table 4 summarizes the Fujita scale.

The F scale is based on tornado damage (primarily to buildings), so there is ambiguity in the scale. For example, a tornado which moves over open country will tend to receive a lower rating than a tornado that strikes a populated area. Since buildings have a wide variation in age, quality of design, and quality of building materials, more uncertainties are thrown into the mix. Tornadoes over open country will probably encounter varying types of vegetation, leading to uncertainties in these cases. Still, the Fujita scale provides a good baseline for classifying tornadoes according to their intensities.

Fujita Damage Scale

F0	Gale Tornado	weak	40-72 mph
F1	Moderate Tornado	weak	73-112 mph
F2	Significant Tornado	strong	113-157 mph
F3	Severe Tornado	strong	158-207 mph
F4	Devastating Tornado	violent	208-260 mph
F5	Incredible Tornado	violent	261-318 mph

Table 4: The Fujita tornado damage scale.

Tornado/Funnel Cloud Look-Alikes

Experienced spotters are probably aware that a number of features (both natural and man-made) can bear a resemblance to a tornado or funnel cloud. Some of these features include rain shafts and scud clouds. Some of the man-made features include smoke from oil flares and factories. If a suspicious-looking cloud formation is observed, watch it for a minute or two. Look for **organized rotation** about a **vertical** or **near-vertical axis**. Figure 34 depicts a number of tornado look-alikes.

Another phenomenon which must be discussed is the **gustnado**. Gustnados are small vortices which sometimes form along a gust front (figure 35). Gustnados are generally not associated with the updraft area of the storm and do not originate in mesocyclones, so in some ways they are not "legitimate" tornadoes. They can cause damage to lightweight structures and are hazardous to people in the open, though, so they do pose a threat and should be reported to the controller/dispatcher.

Figure 34: Some tornado/wall cloud look-alikes (a) Scud Clouds.

(b) Rain shaft. Photos - NWS, NSSL.

Figure 35: Gustnados are small votices which sometimes form along strong gust fronts. View is to the southwest. Photo - Charles Doswell III.

X. SUPERCELL VARIATIONS

The supercell discussed in chapter IV is considered a "classic" supercell and serves as a baseline when discussing supercell types. Much has been made recently of "low-precipitation" (LP) and "high-precipitation" (HP) supercells, which might lead some to believe that these are truly different kinds of supercells. In actuality, all supercells are fundamentally the same. They all possess a mesocyclone, they are all long-lived, and all are capable of producing extremely dangerous weather. The only difference in these supercells is the amount of visible precipitation which falls out of the storm. Although variations in precipitation will pose different problems for the NWS radar operators and for spotters, the underlying theme is that "a supercell is a supercell, be it LP, classic, or HP."

Low-Precipitation (LP) Supercells

Low-precipitation supercells are most commonly found on the High Plains near the dryline (sometimes they are called "dryline storms"), but they have been documented in the Upper Midwest as well. LP supercells are difficult to detect on radar. The radar echoes are usually small and weak (low reflectivity values). There may not be evidence of rotation within the storm as detected by conventional radar. Figure 36 shows a diagram of an LP supercell. LP storms are fairly easy to identify visually, however. The typical low-precipitation supercell has a translucent main precipitation area. The main storm tower is usually thin, bell-shaped (flared out close to the cloud base), and has corkscrew-type striations on the sides of the tower. Figure 37 illustrates the typical visual appearance of LP supercells.

High-Precipitation (HP) Supercells

High-precipitation supercells can occur in any part of the country. It was once thought that HP supercells only occurred in the Southeast, but they have been documented in the Great Plains as well. HP supercells are easy to detect on radar. They usually have a large radar echo with evidence of rotation within the storm. Figure 38 shows a diagram of an HP supercell. In some high-precipitation supercells, the mesocyclone is displaced to the southeast or east side of the storm. This displacement, coupled with the copious amounts of precipitation falling from the storm, make HP supercells difficult for spotters to identify. The heavy precipitation may obscure some (or all) of the "rain-free" base area and obscure the important cloud features that are found in this area. However, HP supercells will usually have striations around the main storm tower and will probably have a beaver's tail and a mid-level cloud band. Thus, although events under the cloud base will be difficult to discern, ample evidence will exist to confirm that it indeed is a supercell. Figure 39 depicts the visual characteristics of HP supercells.

Hybrid Storms

It is rare for a storm to fit perfectly into one of the four storm categories (discussed in chapter IV) for its entire life. Rather, it is common for a storm to evolve from one storm type to another. It is also common for a supercell's precipitation rate to increase during its life, resulting in its "evolution" from an LP to an HP supercell. See figure 40 for an example of an LP-to-HP "evolution."

One of the more common evolutions a storm may undergo is a multicell-to-supercell transition. Figure 41 contains an example of this transition. As the multicell storm moves along, it may encounter an environment more conducive to supercell formation. One of the updrafts in the cluster may become dominant, and the storm may evolve into a supercell. In fact, numerous supercells with multicell characteristics have been documented!

The multicell characteristics in some supercells may give rise to the **cyclic nature** of some supercells. A cyclic supercell is a supercell which undergoes the mesocyclone formation-tornado formation-RFD formation process a number of times. In the April 3, 1974, tornado outbreak, one supercell produced eight tornadoes as it tracked across Illinois and Indiana. While it is rare for a supercell to produce this many tornadoes, it serves to illustrate the extremely dangerous nature of cyclic supercells. Figure 42 contains an example of a cyclic supercell.

Besides the possibility of a storm "evolving" from an LP to an HP storm, it is also possible for a supercell to have both LP and HP characteristics at the same time. Figure 43 shows an example of such a storm. The main precipitation area, to the right of the storm tower, had a thin, translucent appearance. Beneath the base of the storm, however, a heavy precipitation curtain obscured any important cloud features which may have been present. These LP-HP hybrids are yet another example of the continuous spectrum of storm types that may be encountered in the spotting arena.

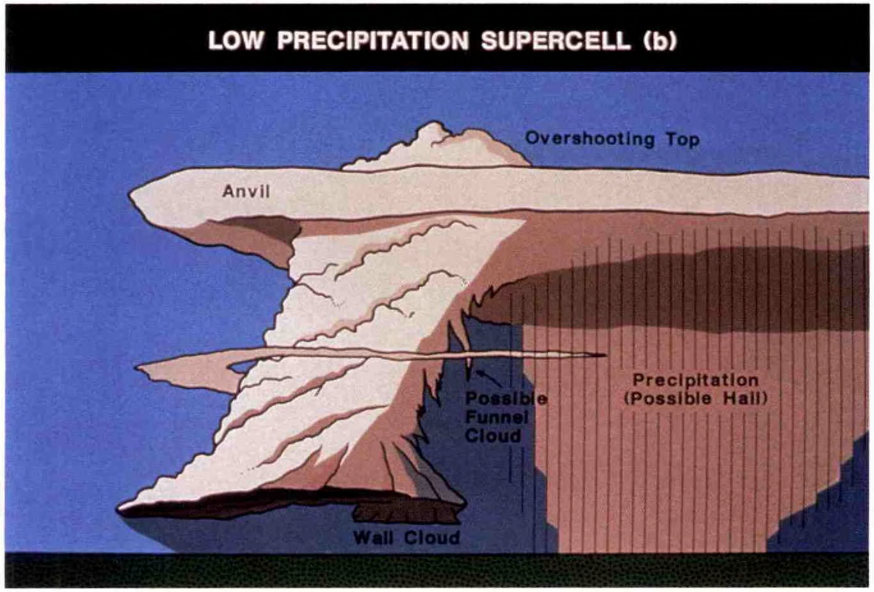

Figure 36: Schematic diagram of a low-precipitation supercell. The main precipitation area to the right of the updraft tower is usually very light.

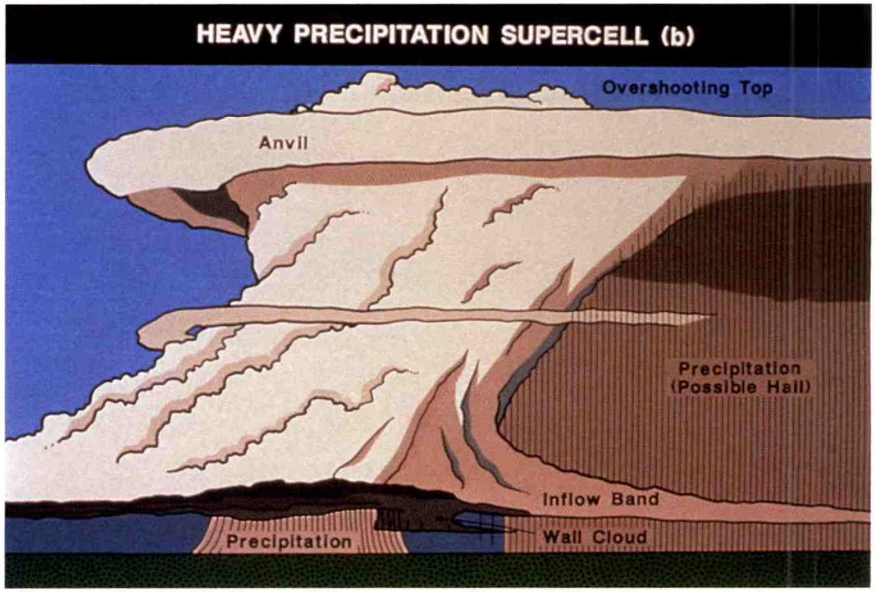

Figure 38: Schematic diagram of a high-precipitation supercell.

Figure 37: Typical appearance of a low-precipitation supercell. View is to the west. Photo - Steve Tegtmeier.

Figure 39: Typical appearance of a high-precipitation supercell. View is to the west. Photo - John McGinley.

Figure 40: LP-to-HP evolution. (a) LP supercell with developing wall cloud.

(b) HP supercell with updraft base nearly totally obscured.
Photos - Alan Moller.

Figure 41: Multicell-to-supercell evolution. (a) Multicell storm with (at least) 6 updraft elements.

(b) Supercell with one dominant updraft.
Photos - Tim Marshall, NSSL.

Figure 42: Cyclic supercell. As tornado #1 dissipates, inflow is refocused into the new wall cloud (right). Tornado #2 then develops from the new wall cloud.
Photos - Gary Woodall.

Figure 43: LP-HP hybrid storm. The "main precipitation area" is translucent, but heavy precipitation is visible beneath the updraft base.
Photo - Gary Woodall.

Acknowledgments

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* Volume 2 - Storm-Scale Analysis.

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