5 Thunderstorms

A thunderstorm is a local storm produced by *cumulonimbus* clouds. The storm itself may be a single cloud or *cell*, a cluster of cells, or a line of cumulonimbus clouds that may extend for hundreds of miles. (Individual cells last for a relatively short period—seldom over two hours.) Thunderstorms are accompanied by lightning and thunder. Lightning is the visible electrical discharge produced by thunderstorms; thunder is the sound produced by rapidly expanding gases along the channel of a lightning discharge.

> "A disastrous thunderstorm accident close to Bowling Green, Kentucky, in 1943 that involved an American (Airlines) DC-3 started a chain of events that eventually led to the first systematic research into thunderstorm behavior. The plane crashed onto the ground either near or under a severe thunder-storm. Buell (C.E. Buell, chief meteorologist, American Airlines 1931-1946) initiated a letter to the Civil Aeronautics Board pointing out the appalling dearth of understanding of what actually occurs inside a thunderstorm, as evidenced by the accident investigation. He recommended a massive research effort be organized to probe into thunderstorms and document their internal structure," according to Peter E. Kraght in Airline Weather Services 1931-1981.

Thunderstorm formation requires three atmospheric conditions:

- sufficient water vapor (Moisture),
- an initial lifting mechanism (Vertical Motion), and
- unstable air (Stability).

Should any of the three elements be missing, thunderstorms will not develop.

Rule of Thumb: Look for surface dewpoints of 10°C (50°F) for sufficient moisture to initiate thunderstorms. But, remember moisture is only one element needed to produce thunderstorms.

The first ingredient for thunderstorms is water vapor—moisture. Most often moisture comes from a maritime air mass. Air masses were discussed in chapter 1. Moisture can be transported thousands of miles.

The second component for thunderstorm development is an initial lifting mechanism. In chapter 2 we discussed vertical motion. Any of those phenomena can produce the required lifting. Most often, lifting is produced by a frontal surface, sloping terrain, convergence, or surface heating—convection. However, upslope and low-level warm-air advection may be all that's necessary to trigger thunderstorms.

The third element for thunderstorms is unstable air. Atmospheric stability was presented in chapter 2. Without an unstable air mass, a cap or lid prevents the upward vertical motion essential for thunderstorm development.

Thunderstorms progress through three stages (Fig. 5-1) called the *life cycle*:

- towering cumulus,
- mature, and
- dissipating.

Lifting creates an initial updraft. At the lifted condensation level adiabatic cooling results in condensation and the beginning of cloud formation—*towering cumulus stage*. Cloud droplets are small but grow into raindrops as the cloud builds.

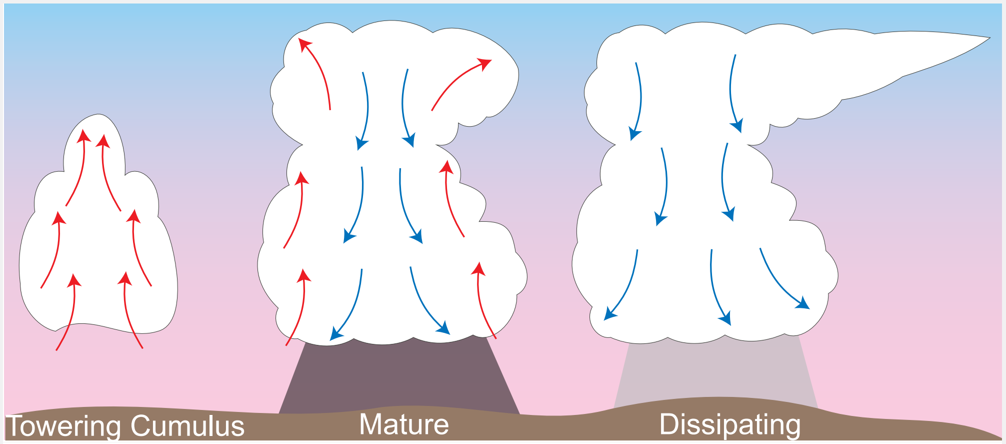


Fig. 5-1. *Thunderstorms progress through three stages called the life cycle.*

Condensation releases latent heat which partially offsets adiabatic cooling in the saturated updraft, increasing buoyancy. The rising air is warmer than the surrounding air. Increased buoyancy drives the updraft still faster drawing more water vapor into the cloud. The updraft becomes self-sustaining in the unstable air.

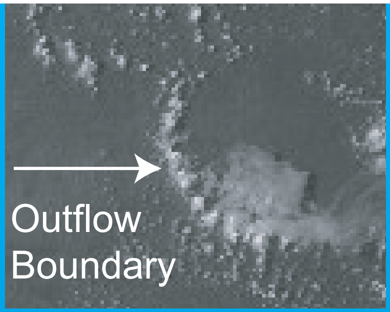
Without sufficient water vapor, initial lifting may not be sufficient to sustain continued vertical motion. In a stable atmosphere, vertical motion ceases and stratiform clouds form.

As the cloud towers upward, the updraft cools adiabatically until the air in the storm becomes colder than the surrounding air. This difference in temperature together with the increasing weight of water drops and ice particles retards upward vertical motion—ultimately turning into a downdraft or outflow. The change of flow may directly reverse the updraft or may arch outward as an outflow allowing the updraft to continue unabated.

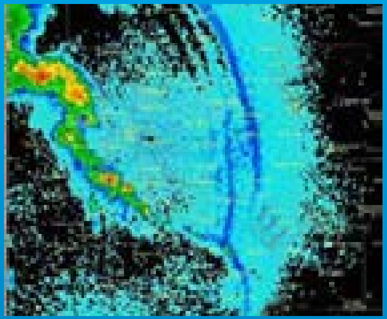
In the *mature stage* water drops are ejected from the updraft or become so large the updraft can no longer support them and begin to fall. The mature stage begins when rain or VIRGA (Variable Intensity Rain Gradient Aloft—rain that evaporates before reaching the ground) first falls from the bottom of the cloud. Updrafts continue to gain strength in the early mature stage.

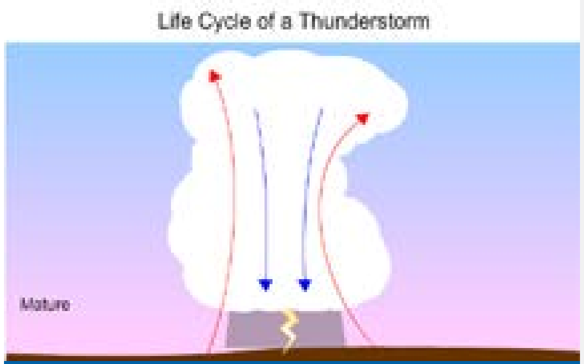
The mature stage occurs roughly 10 to 15 minutes after the cloud builds above the freezing level. As the water drops fall, they pull air down—a major factor in the formation of downdrafts in the mature stage. The air dragged down by the falling rain cools the surrounding air, which accelerates downward motion. Throughout the mature stage, downdrafts continue to develop and coexist with updrafts. Maximum updrafts tend to be found in the upper two-thirds of the storm. The mature state represents the most intense period of the storm. Lightning activity is greatest and hail, if present, most often occurs in the mature stage due to the coexistence of both up and downdrafts.

The *dissipating stage* begins when water vapor is cut off and downdrafts predominate. The dissipating stage is characterized by weak downdrafts throughout the cloud. Condensation gradually decreases, and when all the water has fallen from the cloud or evaporated, the dissipating stage is complete. At the surface all signs of the thunderstorm disappear and any clouds that remain are stratiform.



Outflow boundary may appear on satellite (above) and radar (below—dark blue arcs) images.





"Click" *Life Cycle of a Thunderstorm* to view animation.

Dissipating groups of thunderstorms can produce *outflow boundaries*. An outflow boundary (callout) is a surface boundary left by the horizontal spreading of thunderstorm-cooled air. The boundary is often the initial lifting mechanism needed to generate new thunderstorms.

Analogy

> Think of a thunderstorm as an engine. The "starter" (initial lifting) creates an updraft to begin the process. "Fuel" consists of water vapor. "Ignition" results from initial condensation. Latent heat provides the "energy" to drive the storm. The "engine" now becomes self-sustaining. It no longer depends on the "starter" or initial lifting. "Combustion" products consist of clouds and water drops. Downdrafts or outflow are the "exhaust" products. The storm throttles down.

Thunderstorm Hazards

Thunderstorms produce just about every weather hazard known to aviation. These include wind shear turbulence (strong up and downdrafts, microburst, and strong, gusty surface winds), icing, low ceilings and visibilities, precipitation (including hail), VIRGA, altimeter errors, lightning, tornadoes, and heat bursts. These hazards are illustrated in Fig. 5-2.

Case Study

> Just when you think you've seen all the hazards associated with thunderstorms something different comes up. Take the experience of U.S. Air Force Lt. Col. William Rankin. He was forced to bail out of his jet at 47,000 ft over Virginia—you guessed it into a raging thunderstorm. As he fell through the storm he plummeted to 10,000 ft before opening his chute. For the next 40 minutes the Colonel rode out the storm's up and downdrafts, with lightning flashing all around. He finally wound up in some trees about 65 miles from where he bailed out! His adventure gives a new meaning to "sport parachute jumping."

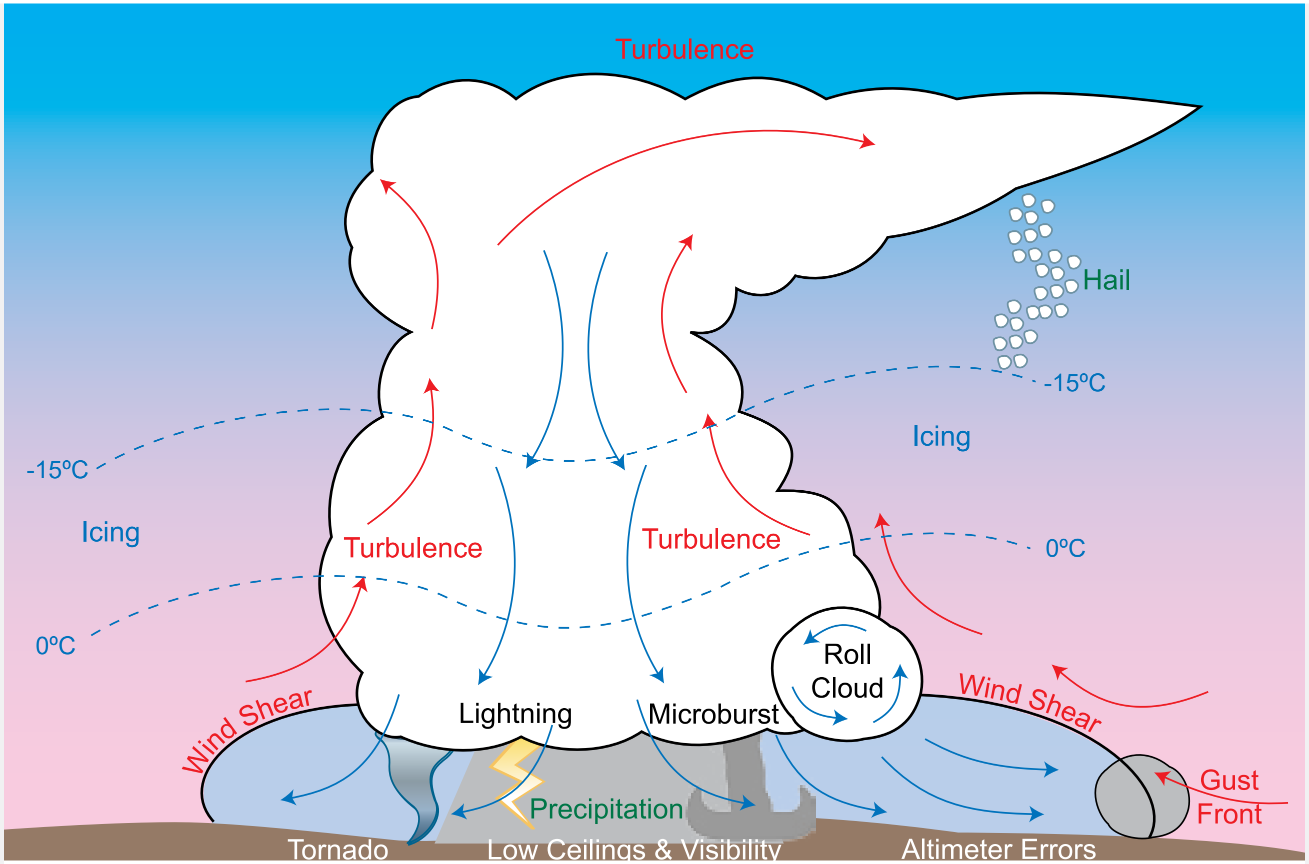


Fig. 5-2. *Thunderstorms contain just about every weather hazard known to aviation; hazards extend well beyond the visible cloud.*

Turbulence

Vertical motion (up and downdrafts), the basic structure of the storm, generates wind shear. Wind shear turbulence exists in every part of, and adjacent, to the storm. Up and downdrafts affect the aircraft's altitude as it flies above, through, beneath, or adjacent to the storm. It is virtually impossible to hold altitude and altitude excursions of several thousand feet are not unusual. Thunderstorm wind shear occasionally produces structural damage. The most significant and frequent turbulence occurs near the freezing level.

Updrafts are the main feature of the towering cumulus stage. At the edge of a cloud, the mixing of cloud and clear air often produces strong temperature gradients associated with rapid variation in vertical speed and associated turbulence. Updrafts may exceed 3000 feet per minute (fpm) and extend from the surface to several thousand feet above the visible cloud top.

Both up and downdraft exist in the mature stage. Updrafts may exceed 6000 fpm—9000 fpm in a supercell; downdrafts greater than 3500 fpm can develop. Hazardous turbulence can occur in clear air 20 miles laterally. Downdrafts below the cloud base create a significant hazard beneath the storm. Downdrafts predominantly persist in the dissipating stage.

Case Study

> It was early afternoon east of Albuquerque, New Mexico. We were ferrying a Cessna 172 from Alabama to California. High base cumulus were developing. We encountered 2000 fpm up and downdrafts, with light to moderate turbulence—even though we weren't directly below the clouds (callout). This illustrates what can be expected during the towering cumulus stage. We could see the thunderstorms building to the west and decided to spend the night. The following morning was clear, cool, and smooth for the next leg of our journey.

Rain cooled air within the thunderstorm produces a concentrated rain or VIRGA shaft, producing a strong downdraft. The downdraft has a sharp edge and forms a ring vortex upon contact with the ground, then spreads out as a gust fronts. The downdraft continues as an expanding outflow—particularly hazardous to aircraft during takeoff, approach, and landing. Thunderstorm downdrafts and outflow have been categorized as:

- downdrafts,
- downbursts—also known as macrobursts; and,
- microbursts.

Downdrafts are columns of air with vertical speeds less than 720 feet per minute; they affect an area with a diameter greater than three miles and can affect areas more than 15 miles from their parent cell. A *downburst* is a severe downdraft with a vertical speed greater than 720 fpm. A *microburst* has a vertical speed greater than 720 fpm and covers an area less than two-and-a-half miles across. Downbursts and microbursts can reach to within 300 ft of the surface before spreading out over the ground. Destructive wind shear occurs, on average, in 1.5% of all thunderstorms.

A microburst consists of a small-scale, severe, storm downburst less than two-and-a-half miles across, as illustrated in Fig. 5-3. Microbursts are characterized by precipitation or dust curls carried back up toward the cloud base, horizontal bulging near the surface in a rain shaft forming a foot-shaped prominence, an increase in wind speed as the microburst expands over the ground, and abrupt wind gusts.

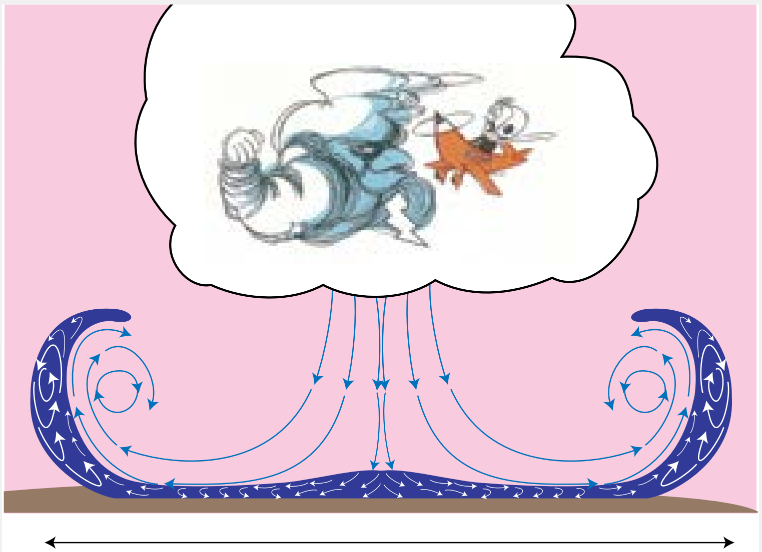


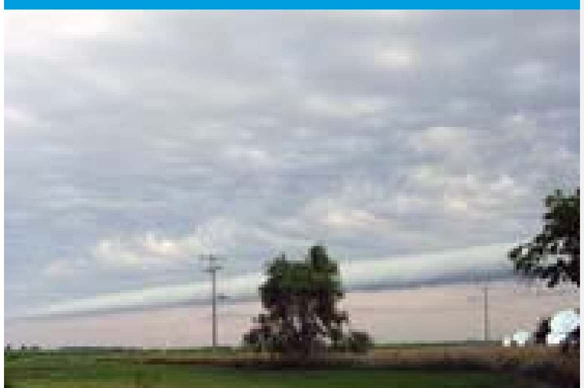
Fig. 5-3. *A microburst consists of a small-scale, severe storm downburst.*

Air flow can be 180° from the prevailing wind, with an average peak intensity of about 45 knots. Microburst winds intensify for about five minutes after ground contact and typically dissipate about 10 to 20 minutes later. Microburst wind speed differences of almost 100 knots have been measured. Some microburst events are beyond the capability of any aircraft and pilot to recover. Although normally midafternoon, midsummer events microbursts can occur any time, in any season.

Microbursts can develop anytime convective activity, such as thunderstorms, rain showers, or VIRGA occur, associated with both heavy and light precipitation. Approximately five percent of all thunderstorms produce microbursts. And more than one microburst can occur with the same weather system. Pilots must be alert for additional microbursts—if one has already been encountered or reported—and prepare for turbulence and shear as subsequent microbursts interact.

On August 1, 1983, at Andrews Air Force Base—outside Washington D.C., micorburst wind differences of near 200 knots were observed.

"Click" *Microburst* to view animation.



Roll Cloud

Embedded microbursts are produced by heavy rain from low based clouds in a *wet environment*. A wet microburst might first appear as a darkened mass of rain within a light rain shaft. As the microburst moves out along the surface a characteristic upward curl appears.

Microbursts can also occur in extremely *dry environments* characterized by high cloud bases and low surface humidity. The lack of low clouds does not guarantee the absence of significant wind shear. Microbursts can develop below clouds with bases as high as 15,000 ft. As VIRGA or light rain falls, intense cooling causes the cold air to plunge, resulting in a dry microburst. Anvils of large dryline thunderstorms can produce high-level VIRGA and dry microbursts. High based thunderstorms with heavy rain are of particular concern.

A *roll cloud* often marks a low-level turbulent/wind shear zone. The result of evaporative cooling, roll clouds are most prevalent with fast moving cold fronts or squall lines. A first gust or gust front precedes the thunderstorm. Thunderstorms typically move over the ground at 20 to 30 knots, gust fronts move at about the same speed. The cumulative speed of gust fronts may travel over the surface at between 40 and 60 knots!

Some of the worst wind shear associated with thunderstorms, outside of actual storm penetration—and we literally don't want to go there—results from the gust front, downdrafts and outflow winds. The first gust forms along the leading edge of large domes of rain-cooled air that result from the cool downdrafts and outflow from an individual thunderstorm cell. The boundary between the cool downdraft outflow and the warmer thunderstorm inflow produces the characteristic wind shift, temperature drop, and gusty winds that precede the thunderstorm.

Usually, the first gust precedes the arrival of the roll cloud and onset of rain as the thunderstorm approaches. Frequently it stirs up dust and debris as it plows along, signaling the thunderstorm's approach. The strength of the first gust is frequently the strongest observed surface wind during the storm. These winds can change direction by as much as 180° and reach speeds of 100 knots as far as 10 miles ahead of the storm. Gust speeds may increase by as much as 50% between the surface and 1500 ft, with the greatest increase occurring in the first 150 ft. A clue to the presence of the first gust downdraft or outflow is dust or roll clouds, or intense rainfall. Avoided these areas!

Gustnado

> A gustnado describes a funnel cloud that develops along the gust front—not a true tornado. The gustnado receives its initial rotation from the shift in wind directions across the gust front. Cold, dense air behind the gust front lifting warm air ahead imparts a rotating motion in the wind shear zone. They are usually only visible as a debris cloud or dust whirl near the ground. Wind speeds can react 50 to 70 knots.

Avoid takeoff or landing when a thunderstorm is within about 20 miles of the airport. This is the region of the strongest and most variable winds. Exercise caution following thunderstorm passage. A strong, gusty outflow boundary may follow the storm.

Altimeter Errors

Altimeter errors may exceed 100 ft. Pressure typically falls rapidly with the approach of a thunderstorm, rises sharply with the first gust and the cold downdraft and heavy rain showers, falling back to normal as the storm passes. This cycle of pressure change may occur within 15 minutes.

Heat Burst

Just when you think you've heard all the hazards associated with thunderstorms something else comes up. Carolyn Kloth, retired NWS (AWC) forecaster, has proposed that a heat burst may produce another thunderstorm hazard for aviation—high density altitude. Heat bursts occur when thunderstorm downdrafts run out of raindrops—stopping evaporative cooling. The downdrafts warm by compression as the air descends. Heat bursts increase turbulence and wind shear, develop in radar echo free air, and affect the pressure altimeter.

Case Study

> In 1951 at Perrin AFB, Texas a morning thunderstorm produced a spectacular heat burst. The morning low was 66°F as the storm approached. In 15 minutes, the temperature rose to 85°F, finally reaching 98°F by mid-morning.

“Hail has been encountered as high as 45,000 feet in completely clear air and may be carried up to 20 miles downwind from the storm core.” (*Weather for Aircrews*, Air Force Handbook 11-203, 1 March 1997)

Hail encounterred in *clear air* beneath the anvil of a thunderstorm.

Icing

Thunderstorms produce a significant icing hazard. Storms contain large amounts of liquid moisture—even though rain may not be falling. Updrafts support abundant liquid water. When carried above the freezing level, liquid droplets become supercooled. Large supercooled water droplets produce clear icing. The amount of liquid water decreases above the freezing level where snow becomes more predominant; although, supercooled water exists everywhere above the freezing level.

Thunderstorm clouds are usually limited in diameter. However, due to abundant large supercooled water droplets even a short duration encounter can result in severe icing. Expected the most significant icing between the freezing level and -15°C. On rare occasions icing has been encountered in thunderstorms at altitudes of 30,000 to 40,000 ft in temperatures below -40°C.

Precipitation, and Low Ceiling and Visibility

Thunderstorms can produce heavy, showery precipitation in the form of rain or snow, and hail. (Although, not all thunderstorms contain hail.) High based thunderstorms may only produce VIRGA. Thunderstorms may result in ceilings less than 1000 ft and visibility less than one mile, often accompanied by mist and fog. Pilots should infer possible IFR weather with any report or forecast of thunderstorms. In extreme cases thunderstorms have been known to produce zero-zero ceilings and visibilities!

Hail can be one of the most significant thunderstorm hazards. Supercooled drops above the freezing level begin to freeze. Once frozen, other drops accrete and freeze—the hailstone grows. This cyclical pattern continues as the hailstone moves from updraft to downdraft and back again until the updraft can no longer support the hailstone’s weight. Eventually the hailstones fall. As they descent through the freezing level, they begin to melt.

The largest hailstones and greatest frequency occur in a mature, severe thunderstorm—usually at altitudes between 10,000 and 30,000 ft. Hail typically falls in streaks or swaths beneath the storm, covering an area about one-half mile long and five miles wide. Hail typically occurs in the rain area within the cloud, under the anvil, or other overhanging cloud. Hail is frequently carried aloft and tossed out the top or side of the cloud by updrafts and may be encountered in clear air up to four miles from the cloud. Hail frequently exists in thunderstorms even though it is not reported at the surface.

Hail can cause severe damage to aircraft in flight as well as objects on the ground. Blunted leading edges, cracked windscreens, and frayed nerves are common results of a hail encounter. There have been several multiple turbine engine power-loss and instability occurrences, forced landings, and accidents attributed to operating aircraft in extreme rain or hail. Investigations reveal that rain or hail concentrations can be amplified significantly through the turbine engine core at high flight speeds and low engine power. Like most thunderstorm hazards, avoidance may be the only safe alternative.

Lightning

Lightning can cause temporary blindness making aircraft control by reference to instruments difficult. Although lightning strikes an airplane approximately every 3000 hours, significant damage is the exception. Lightning can damage navigational and electronic equipment, burn wires, magnetize airframes, destroy composite structures, fuse control surfaces, cause turbojet compressor stall and flameout, and, although rare, ignite fuel tanks. Direct lightning strikes may result in small punctures in the aircraft's skin.

Case Study

> An Air Force commander ordered a KC135 to penetrate a HEAVY intensity thunderstorm to refuel an SR71. The pilot, who was also a meteorologist, had always wondered about the diameter of a lightning bolt. You guessed it! A lightning strike punched a four inch diameter hole in the radome. (Allegedly, the commander who ordered the thunderstorm penetration was soon looking for new employment.)

Lightning is found throughout and adjacent to the thunderstorm cloud, but is most frequent and severe from the freezing level up to about -10°C. The aircraft, like automobiles, typically insulate passengers from lightning hazards.

The only known incident of lightning downing a jetliner occurred on December 8, 1963. Over Elkton, Maryland, lightning struck the aircraft, exploding three of its fuel tanks. Eighty-one people perished.

The name “tornado” may have originated with the Latin word tornare—to turn; or it may have been corrupted from the Spanish tornado—thunderstorm.

In general, the greater the amount of rain and hail the greater the production of lightning. In a storm cell up and downdrafts create areas of different electrical potential. One theory proposes that a typical cloud has three areas of charge. The main area of negative charge occurs at around 19,000 ft, approximately 3000 ft thick. A positive area extends higher in the cloud well above the freezing level. Another area of negative charge exists in the ice crystals at the top of the cloud. Studies show the most active area at temperatures between +11ºC and –6ºC, with some type of precipitation. However, lightning may occur at any level within the thunderstorm or even outside the thunderstorm itself. Lightning can occur in the clear air around the top, sides, and bottom of a storm. Pilots can reduce the risk of lightning strikes by avoiding flight within 8ºC or 5000 ft of the freezing level. Lightning discharges can sometimes jump 10 miles or more from the storm. Skies overhead may be clear. Thus, lightning bolts can, on occasion, appear as “bolts from the blue.”

Another electrical phenomenon associated with thunderstorms is corona discharge, colloquially: St. Elmo’s fire. St. Elmo’s fire becomes visible as bluish static electric streaks dancing across the windscreen. St. Elmo’s fire is not a hazardous. Aircraft flying through or in the vicinity of thunderstorms often develop corona discharge streamers from antennas and propellers, and even from the entire fuselage and wing structure. It produces the so-called precipitation static (p-static). P-static, however, usually only affects low frequency radio communications and navigation. To prevent or reduce p-static, aircraft are equipped with static discharge wicks on the trailing edges of the control surfaces. Some pilots have reported precipitation static and St. Elmo’s fire as an indicator of a significant charge on the airframe preceding an imminent lightning strike. P-static wicks must not be confused with lightning protection devices, although they may serve as an exit point for lightning and reduce damage to the aircraft.

Tornadoes

Tornadoes are produced by severe thunderstorms. They are whirlpools of air, clouds, and debris ranging in diameter from 100 ft to half a mile. Pressure is extremely low in the center of the small, concentrated vortex. Tornado winds probably reach 200 to 300 knots; although based on damage patterns, winds of over 400 knots are indicated. Tornadoes appear as funnel-shaped clouds from the base of a thunderstorm and usually move at 25 to 50 knots. Their paths range from a few miles to probably less than 50

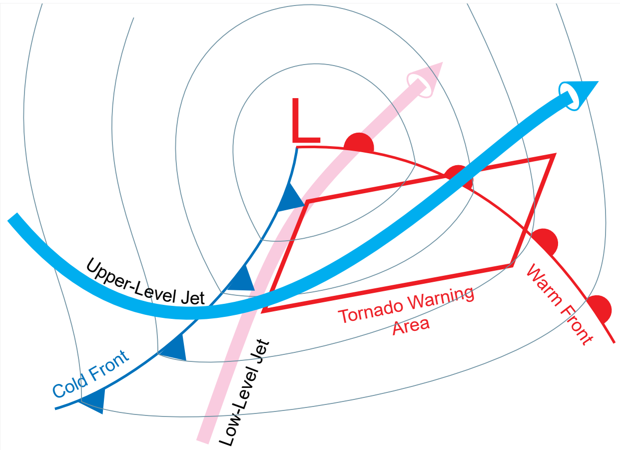


Fig. 5-4. *Typical synoptic pattern for tornadoes in the central United States.*

miles; although, frontal systems and squall lines can produce a series of tornadoes that can cover hundreds of miles. Their exact path is erratic and unpredictable.

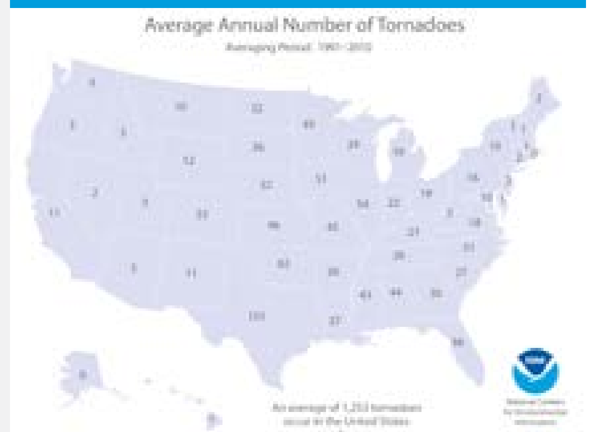
Figure 5-4 illustrates the typical synoptic situation for tornadoes in the central U.S. A low-level jet of moist air feeds the system from the south. The upper-level tropopause jet acts like a vacuum sucking up the moist air. The red-line box shows the typical location where tornadoes develop.

An average of about 200 tornadoes occurs in the United States each year; about 90% develop ahead of cold fronts. They are not a common factor for the west coast states or the intermountain region. Tornadoes occur most frequently in the great plains' states east of the Rocky Mountains. At times tornadoes occur with isolated thunderstorms, but more frequently are associated with cold fronts or squall lines. Reports or forecasts of tornadoes indicate atmospheric conditions favorable for extreme turbulence.

In 1971 Professor T. Theodore Fujita, along with Allen Pearson, introduced a method to rate the intensity of tornados by the damage caused. This became the "F Scale."
In 2007 the scale was updated. Enhanced F-Scale (EF) winds, and associated damage, are shown in Table 5-1.

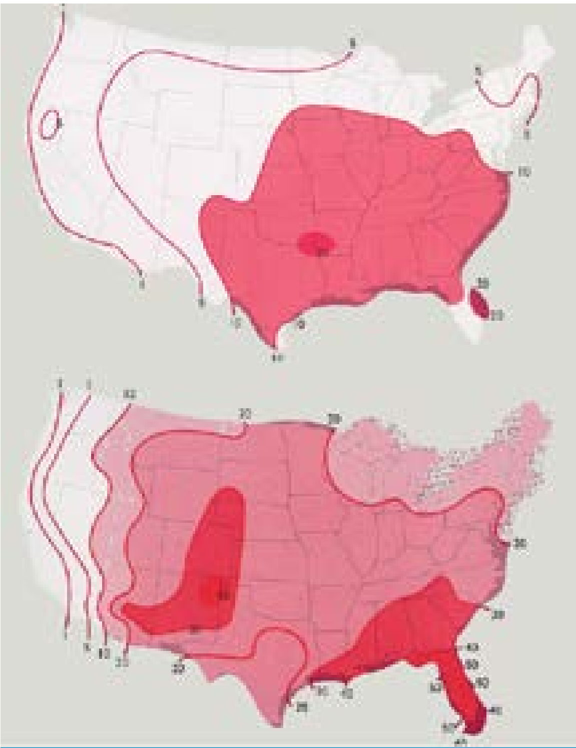
Table 5-1. *Tornado Intensity*

EF	Wind Gust (mph)	Damage Indicator
0	65-85	
1	86-110	small buildings
2	111-135	few family homes
3	136-165	1-wide mobile homes
4	166-200	2-wide mobile homes
5	over 200	large buildings



Thunderstorm Types

Thunderstorm classifications or types are based on development, duration, and severity. Thunderstorms can be divided into:



Average number of days with thunderstorms during the late cool season (top) and warm season (bottom).

- single cell,
- multicell (cluster and line), and
- supercell.

A *single cell*—also called ordinary cell or limited state—thunderstorm consists of only one cell. (Figure 5-1 describes the life cycle of a single cell.) Thunderstorms progress rapidly though the mature stage and are self-destructive, usually lasting from 20 minutes to about an hour and a half. They rarely produce destructive winds, extreme turbulence, or large hail. However, even single cell thunderstorms can produce severe turbulence and icing, and may contain damaging hail.

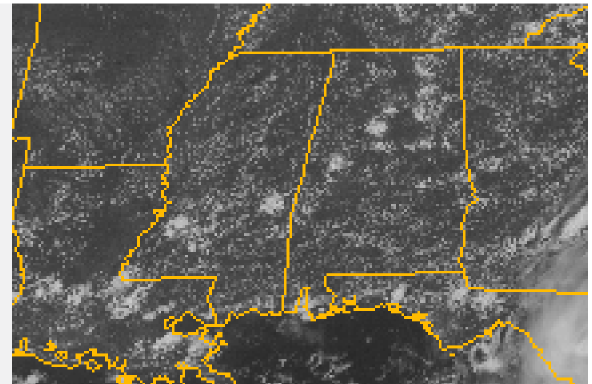
Multicell (clusters and lines)—also known as steady state thunderstorms—consist of cells in various stages. As a cell matures, it drifts downwind and a new cell forms. Multicell thunderstorms may have a lifetime of several hours or more. New cells form if moisture, upward vertical motion, and unstable air exist. Sometimes these thunderstorms form in clusters or lines that can extend for hundreds of miles. Multicell lines may approach or exceed severe limits.

At times storms can develop into *supercells*. Updrafts and downdraft coexist—updrafts may reach 9000 feet per minute (100 knots). The supercell maintains itself as a single entity for hours. Nearly all produce destructive wind, extreme turbulence, severe icing, large hail (over 2 in; swaths over 12 ml); 60% produce funnel clouds and about 25% tornadoes. They can grow to over 60,000 ft, with overshooting tops.

Air Mass Thunderstorms

Air mass thunderstorms form in warm, moist, unstable air not associated with frontal or synoptic-scale lifting—most often initiated by surface heating. Along with surface convective heating, mountains—orographic lifting—provide a primary initial lifting mechanism for the development of these thunderstorms. Convection develops by late morning and increases by mid to late afternoon; then dissipates during the evening hours. Nighttime convection is rare. Weak fronts, and most importantly the passage of upper level troughs, support air mass thunderstorm development. Air mass thunderstorms, most often, are single cell or multicell clusters and typically do not reach severe criteria.

During the warm season the semi-permanent Bermuda High migrates westward, centered in the western North Atlantic. Anticyclonic circulation brings warm, moist, unstable tropical air from the Atlantic Ocean and Gulf of Mexico to the eastern United States (callout). Moist, unstable tropical air, from as far away as the Gulf of Mexico, migrates through New Mexico and Arizona, into Colorado, Utah, Nevada, and California. This air can spread north, reaching as far as Idaho and eastern Oregon and Washington at least two or three times during the season.



Warm season air mass thunderstorms west of the Rockies are most frequent over the higher mountains, deserts, and plateaus (callout).

Multicell/Supercell Thunderstorms

Refer to Fig. 5-5. Multicell/supercell thunderstorms are typically associated with synoptic-scale systems—fronts, low pressure areas, and troughs. Since precipitation falls outside the updraft, the updraft continues unabated. Both updrafts and downdrafts coexist in the mature stage and are about equally balanced—not significantly affecting the other. The mature stage updrafts become stronger and may persist for several hours, considerably longer than that of a single cell. The most significant consequence is that the mature stage continues in a "steady state" and intensifies. These storms may become severe—producing damaging winds, extreme turbulence, and large hail. A severe storm complex, often consists of many developing and dissipating cells,

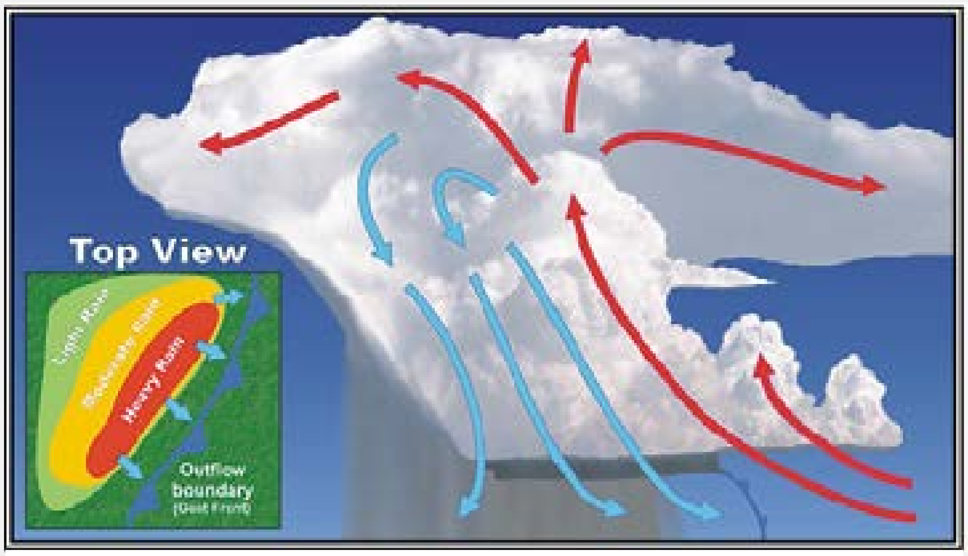


Fig. 5-5. *Multicell thunderstorms result when both updrafts and downdrafts coexist, not significantly affecting the other.*

may last as long as twenty-four hours, and move as far as 1000 miles. Thunderstorms continue until affected by some outside influence or until the mechanics of the thunderstorm cells change, becoming self-destructive.

Figure 5-6 is a portion of a "Legacy" Radar Summary Chart showing an area of developing thunderstorms—the tight contoured area in southeastern Kansas. Storms are developing in the vicinity of a cold front that extends from the central Great Lakes southwestward to a deepening surface low over north central Oklahoma. The strongest cells will develop over Kansas and Missouri in an area of strongest low-level warm-air advection and most favorable moisture and instability. Storms are expected to increase in coverage and intensity and develop into a line along and within the red shaded area.

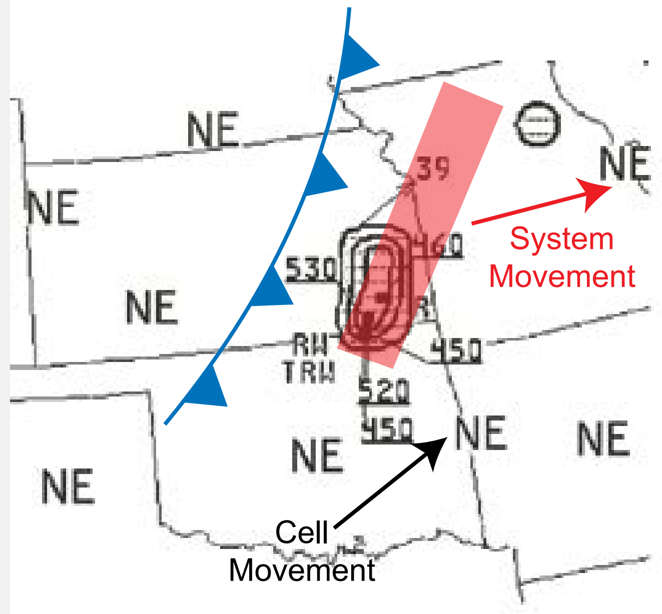


Fig. 5-6. *Storm cell and storm system movement are typically different in multicell thunderstorms.*

Note

The "Legacy" Radar Summary Chart evolved in the 1970s as a graphical summation of radar observations. Computer graphics and electronic transmission of data have replaced this product. The National Weather Service ceased producing the Chart in June 2013.

Supercells are characterized by developing and dissipating cells. In Fig. 5-6 thunderstorms are developing in the southwest, moving from 220° at 39 knots and dissipating in the northeastern portion of the developing line. The system itself is moving from 250° at 25 knots. Different storm cell and system movement are typical with multicell/supercell thunderstorms.

Supercell Thunderstorm

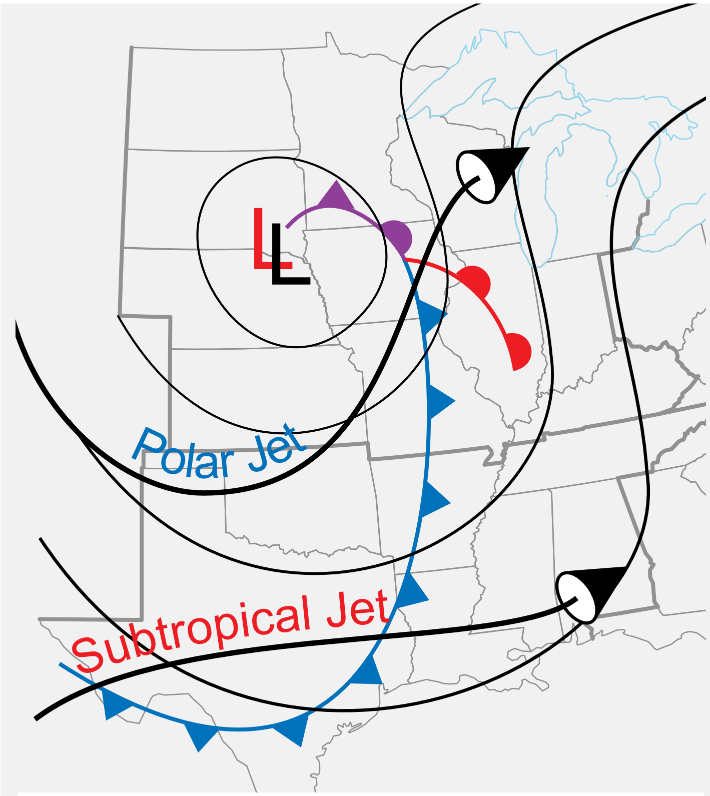
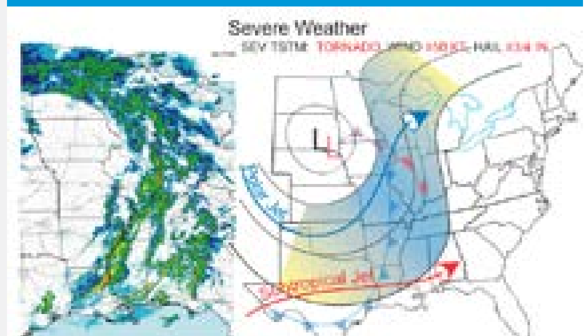


Fig. 5-7. *Late cool season systems often produce the most severe weather.*

Weather in the form of severe thunderstorms and tornadoes is not uncommon east of the Rockies, especially during the second half of the cool season and into the early warm season. Severe weather results from cold air from the north and west interacting with the warm, moist, unstable air from the south and east—greatest temperature contrast. This is also the period when the jet stream is furthest south, enhancing convective activity.

Refer to Fig. 5-7. A surface weather system (shown in color) covers most of the Midwest moving east. At 500 mbs (about 18,000 ft) an upper-level low with its trough-to-ridge flow (shown in black) enhances vertical motion. The polar jet dips through northern Texas and continues northeast into the Great Lakes. The subtropical jet curves through southern Texas and into the southeastern U.S. This is the area of greatest temperature contrast, moisture, and vertical motion. The location of the surface front, upper level wave, and subtropical jet are perfectly placed to produce severe weather.



"Click" *Severe Weather* to view animation.

Squall Lines

When thunderstorms form lines they're often referred to as a squall line. Fig. 5-8 is a composite radar/satellite image. Squall lines can develop along a cold front, but more often appear ahead of the front. They may be produced by wave action 50 to 300 miles ahead of an active cold front. Squall lines result when air aloft flows over a cold front and develops into a wave, much like mountain waves. Where the wave crests—a lifting mechanism, thunderstorms develop in the moist, unstable air.

Squall lines may develop in the central Plains, especially during the late cool and early warm seasons. Behind a cold front, cold, dry continental Polar air pushes down from the north or northwest. To the east warm, moist maritime Tropical air advances from the Gulf of Mexico. Once the thunderstorms develop, the outflow of cold air along the ground initiates lifting which generates new, and possibly more severe storms—an outflow boundary.

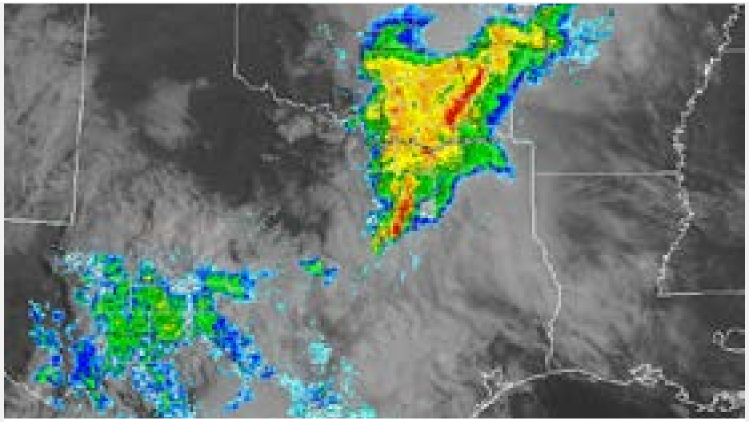


Fig. 5-8. *A squall line is an area of organized, multicell/supercell thunderstorms.*

Mesoscale Convective Systems

Under certain conditions, individual thunderstorms can grow into large, organized convective weather events, collectively known as Mesoscale Convective Systems (MCS). They are typically restricted to the eastern two-thirds of the United States. A *Mesoscale Convective Complex* (MCC) is a large Mesoscale Convective System, covering an area slightly smaller than the state of Ohio. Individual thunderstorms within the complex combine to generate a long lasting, slow moving weather system, producing widespread severe weather and IFR conditions. Mesoscale Convective Complexes develop during late afternoon and persist all night. They are characterized by:

- High moisture content at low levels.
- Low-level warm-air advection.
- Light winds aloft.
- Develop during late afternoon.
- Persist all night.
- Area tends to remain stationary.
- Widespread areas of rain or rain showers.
- Contain heavy rain showers and thunderstorms.
- Produce IFR conditions over wide areas.
- Thunderstorms are usually circumnavigable with storm avoidance equipment.

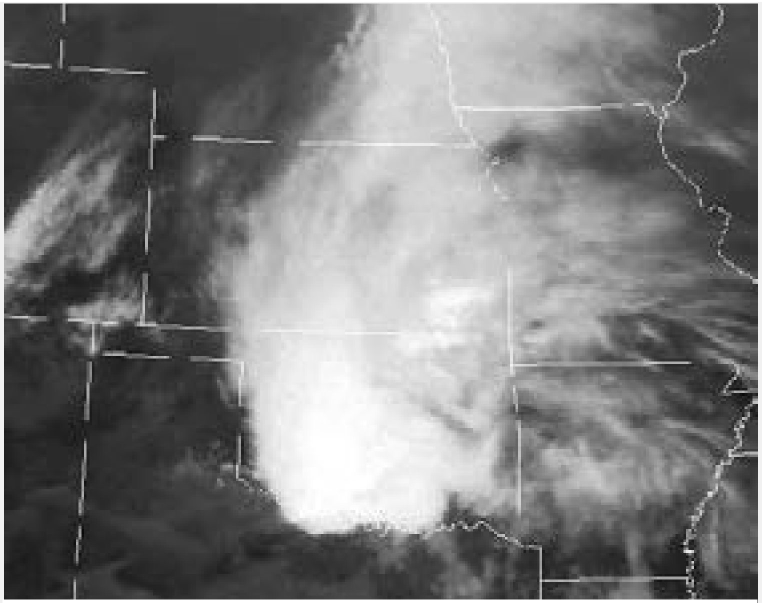


Fig. 5-9. *A Mesoscale Convective System produces severe weather over an extensive area.*

Fig. 5-9 illustrates a Mesoscale Convective System. There are no significant surface weather systems, winds aloft are relatively light, and the area is producing widespread precipitation and areas of severe weather.

The discussion of thunderstorms will continue throughout Part Three and Part Four. Weather radar and convective analysis products will be covered in chapter 12, Weather Radar Products and thunderstorm avoidance in chapter 23, Thunderstorm Avoidance.