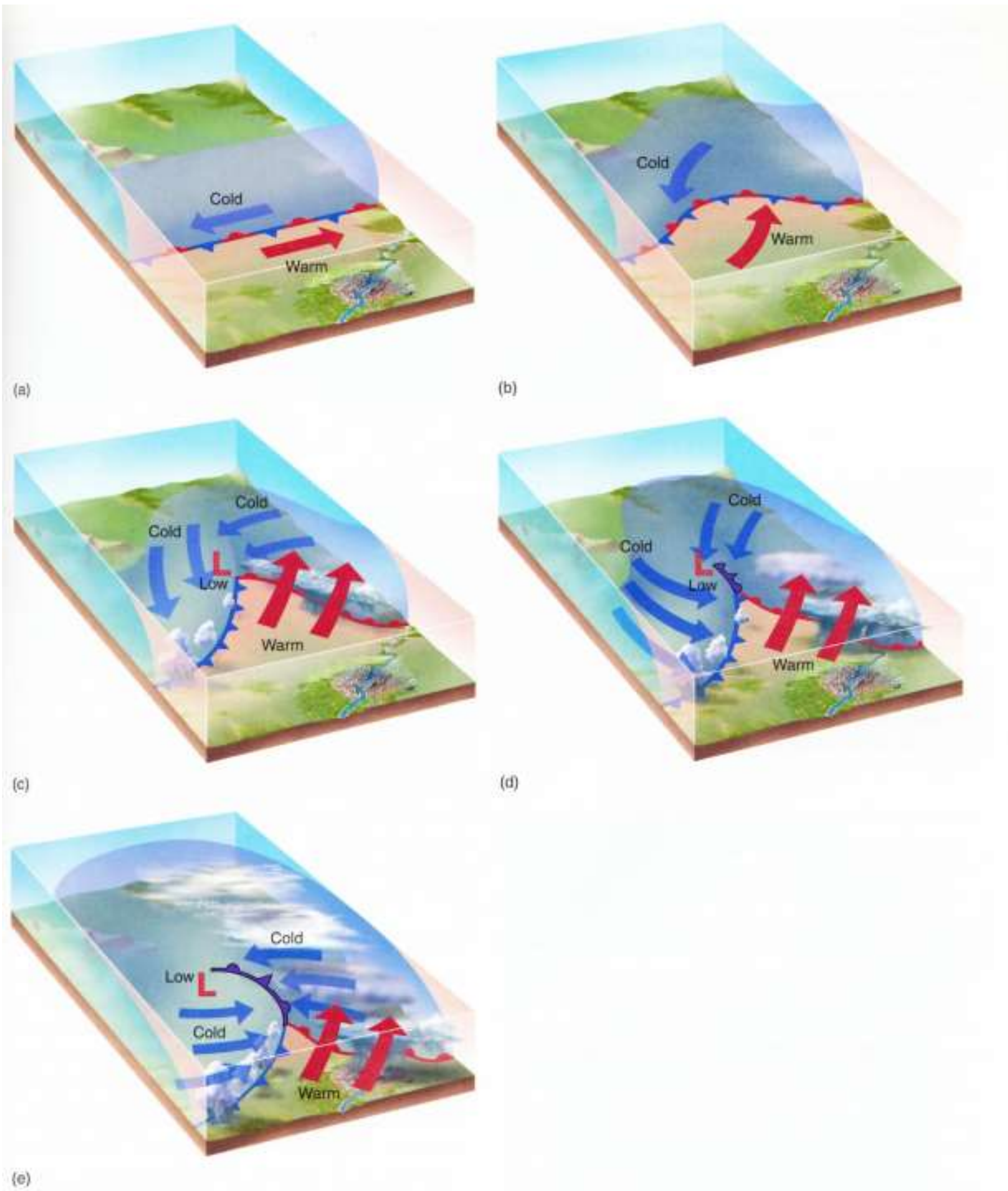
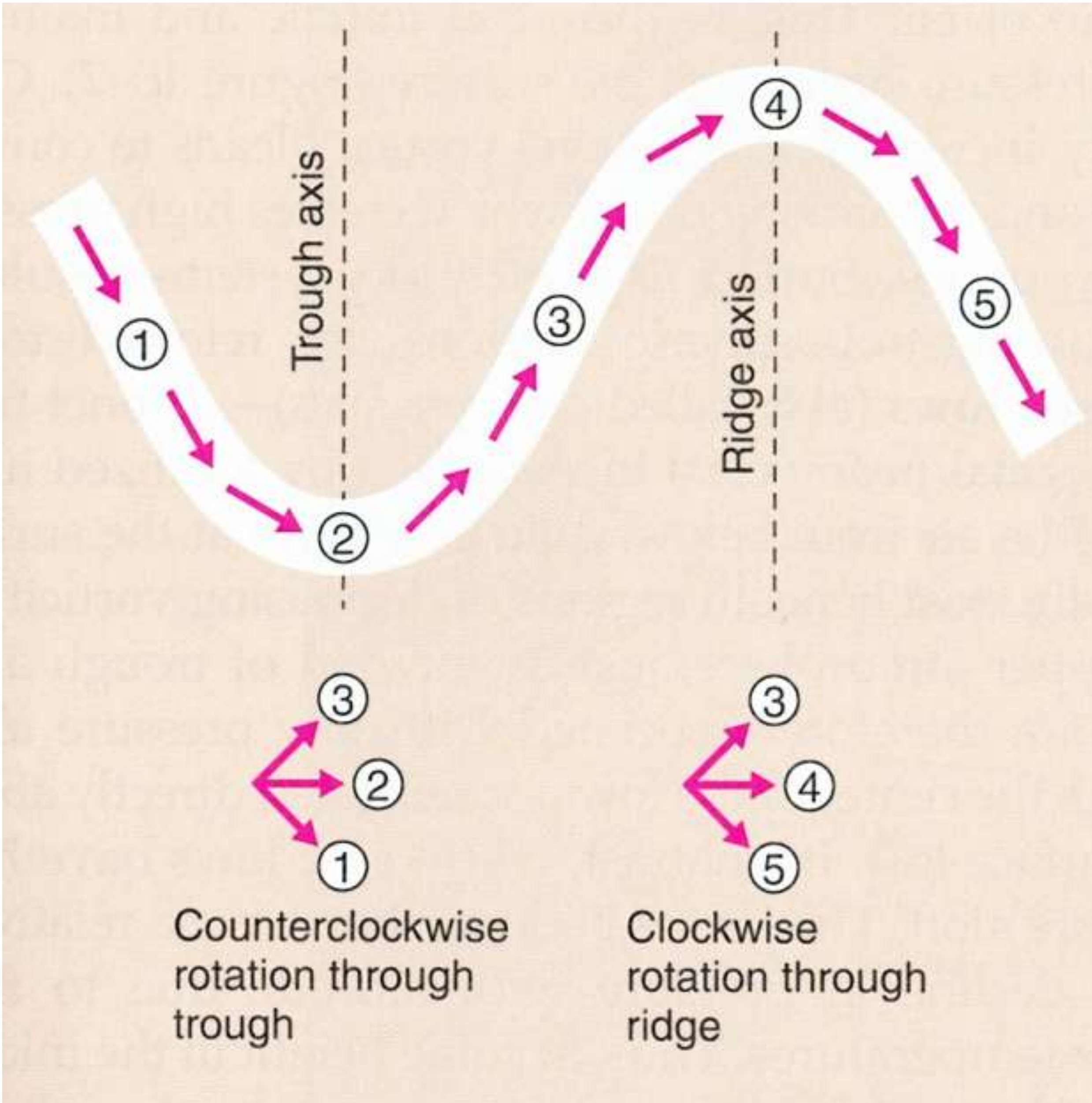
QUICK REVIEW

Last week we were talking about mid latitude or extratropical cyclone formation.

1. Cold polar air moving from east to west (polar easterlies) meets west moving air moving up from the south. As the winds pass one another they start a rotation (Try it with a pencil) and you see that a counterclockwise rotation begins. This forms a low pressure center with the cold air moving around the low and catching up to the warm front leading to an occluded front.



At upper levels, winds are moving geostrophically from west to East which rise and fall as they pass over ridges and troughs



As winds go down into a trough they converge; as the rise up on a ridge they diverge

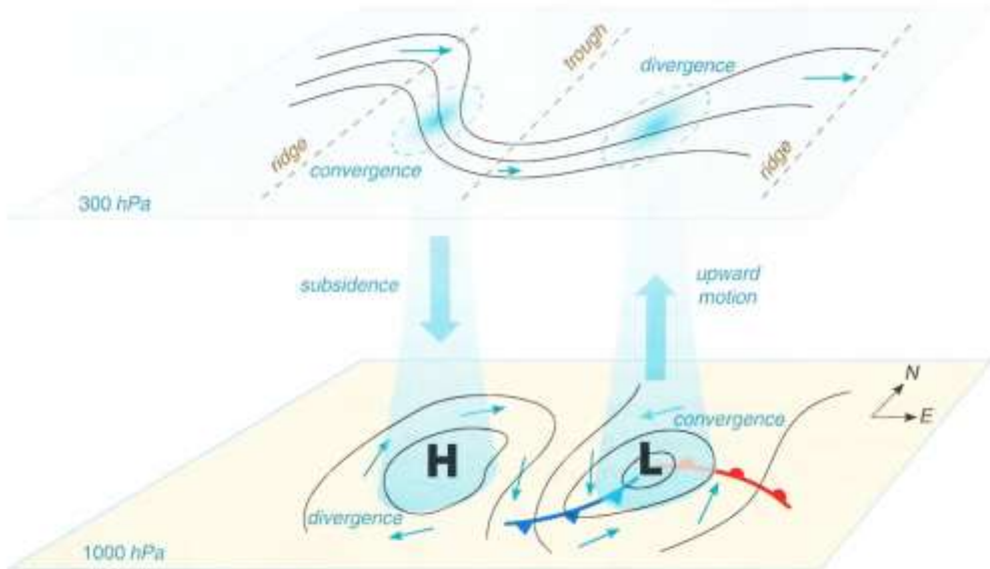


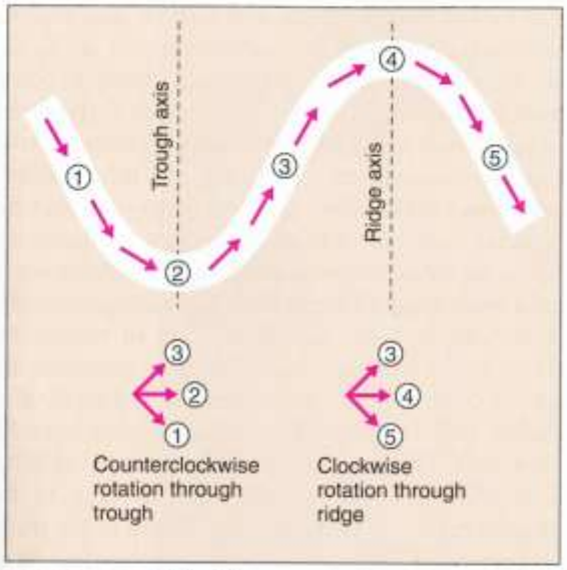
Figure 10.11. Superposition of upper-level convergence and divergence patterns over a surface anticyclone and a deepening cyclone.

The divergence allows the air to move up and out, allowing for the uprising low air to move out, whereas convergence narrows the wind moves down creating the high.

MAJOR STORMS: THUNDERSTORMS, TORNADOS, HURRICANES

ROSSBY WAVES

These are the large waves in the upper troposphere which are caused by the ridges and troughs in the upper atmosphere of the middle latitudes. The largest of these are called Rossby waves or long wave atmospheric waves. They are sometimes fixed in position and sometimes move west to east (rarely east to west). They change positions in latitude in the seasons. They vary in number from 3 to 7 or so. They are where the jet streams are

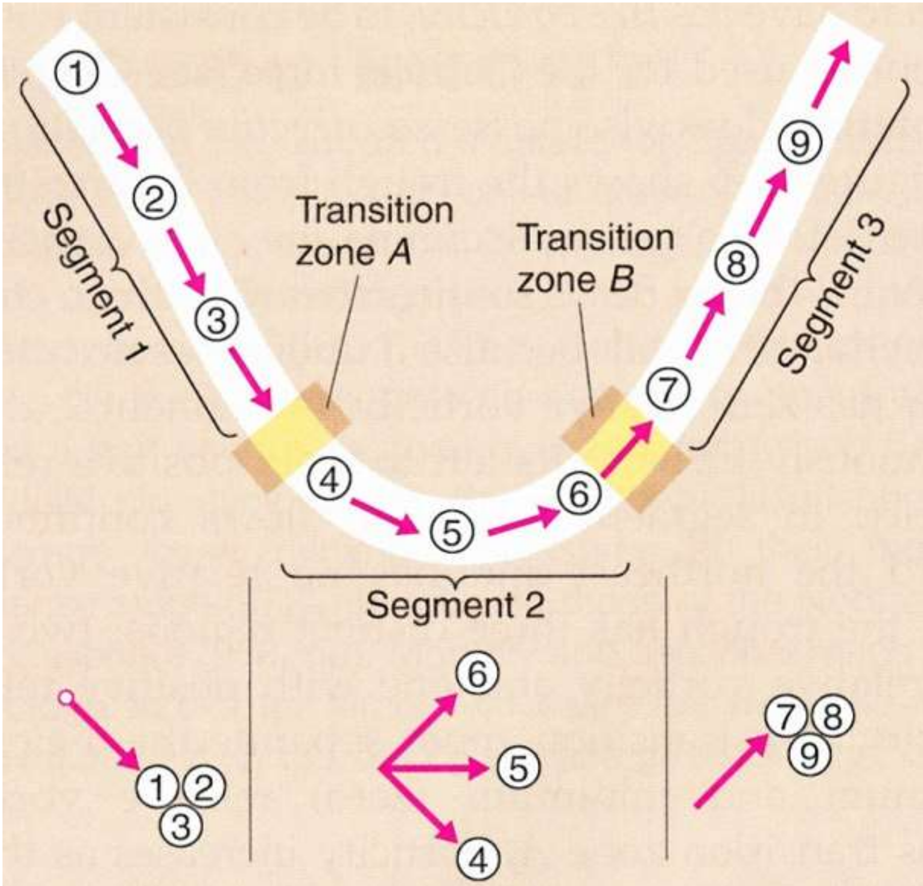


▲ FIGURE 10–4 Vorticity around a Rossby wave. As air flows from positions 1 to 3, it undergoes a counterclockwise rotation. Along the ridge, the air turns clockwise from positions 3 to 5. The bottom of the figure shows the wind vectors representing the flow at the five positions.

The rotation of a fluid such as air or water is known as **vorticity**. Counterclockwise rotation is called positive vorticity, and clockwise rotation is called negative vorticity.

In Segment one the air flows southeastward with no change in direction or speed so it has no vorticity. In segment 2 it turns to the left and yields POSITIVE (COUNTERCOCKWISE) vorticity. In segment three it move northward with no rotation = 0 vorticity.

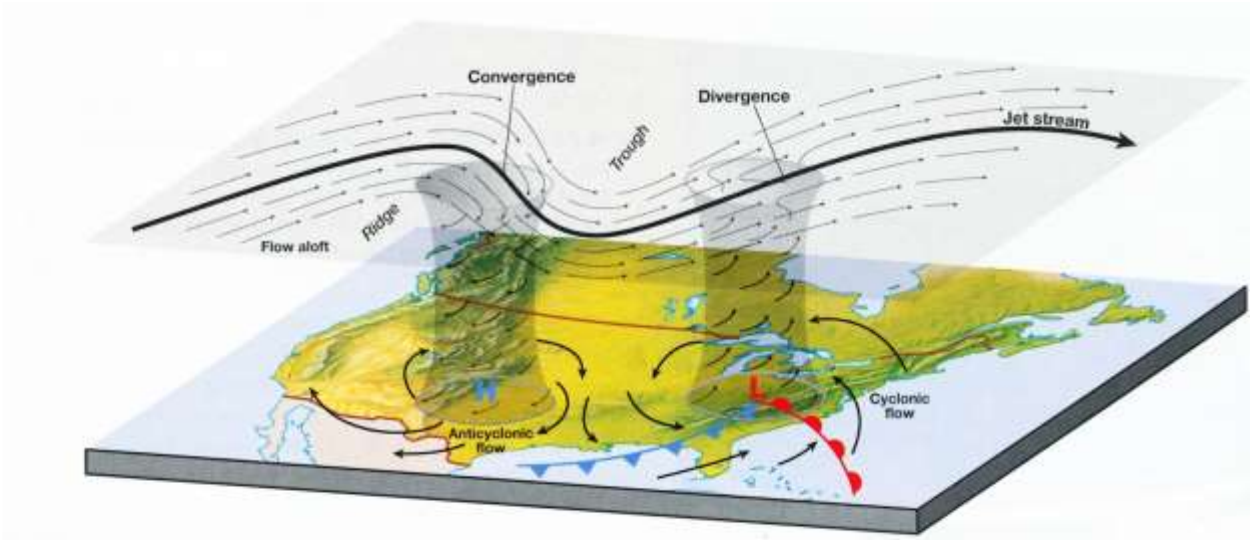
Remembering conservation of angular momentum, as the air moves into segment 2 the horizontal area is decreasing leading to convergence, therefore the "radius" is decreases and its speed or vorticity increases. This causes air to be forced down creating the high pressure center below it.



As the air enters an area approaching a ridge, there is decreasing vorticity casing divergence which brings air up with a low pressure below it.

Surface LOW PRESSURES RESULTING FROM UPPER ATMOSPHERE MOTIONS ARE CALLED DYNAMIC OR COLD CORE LOWS as opposed to THERMAL LOWS CAUSED BY HEATING OF AIR FROM BELOW.

As the wind enters segment 4 the horizontal area in increasing which leads to divergence



THUNDERSTORMS

There are several kinds of thunderstorms, the simplest of which is an (1) AIR MASS thunderstorms. Another is the (2)SEVERE THUNDERSTORM(S) which are clusters of thunderstorms and are called (2a) MESOSCALEE CONVETCTIVE SYSTEMS (MCSs) In some cases they occur in linear bands and are called (2a1) SQUALL LINES. Other times they appear in circular or oval clusters known as (2b)MESOSCALE CONVECTIVE COMPLEXES (MCCs) and the last kind is the (3)SUPERCELL STORM

Type	Appearance	Vertical Wind Shear	Chance of Severe Weather
Air mass/ ordinary single-cell	"Popcorn" in visible satellite image	Small	Unlikely
Multicell	MCC: state-sized circular cloud in infrared satellite image	Small	Likely (nontornadic high winds)
	Squall line: line of thunderstorms in radar or satellite images	Moderate	Likely (20% of tornadoes from nonsupercell storms)
Supercell	Hook echo in radar reflectivity image	Large	Very likely (80% of tornadoes from supercells)

LI	Stability	Interpretation (if Thunderstorms Form)
>0	Stable	Thunderstorms unlikely without strong lifting mechanism
0 to −3	Marginally unstable	Severe thunderstorms unlikely
−3 to −6	Moderately unstable	Severe thunderstorms possible
−6 to −9	Very unstable	Severe thunderstorms probable
<−9	Extremely unstable	Severe thunderstorms very likely

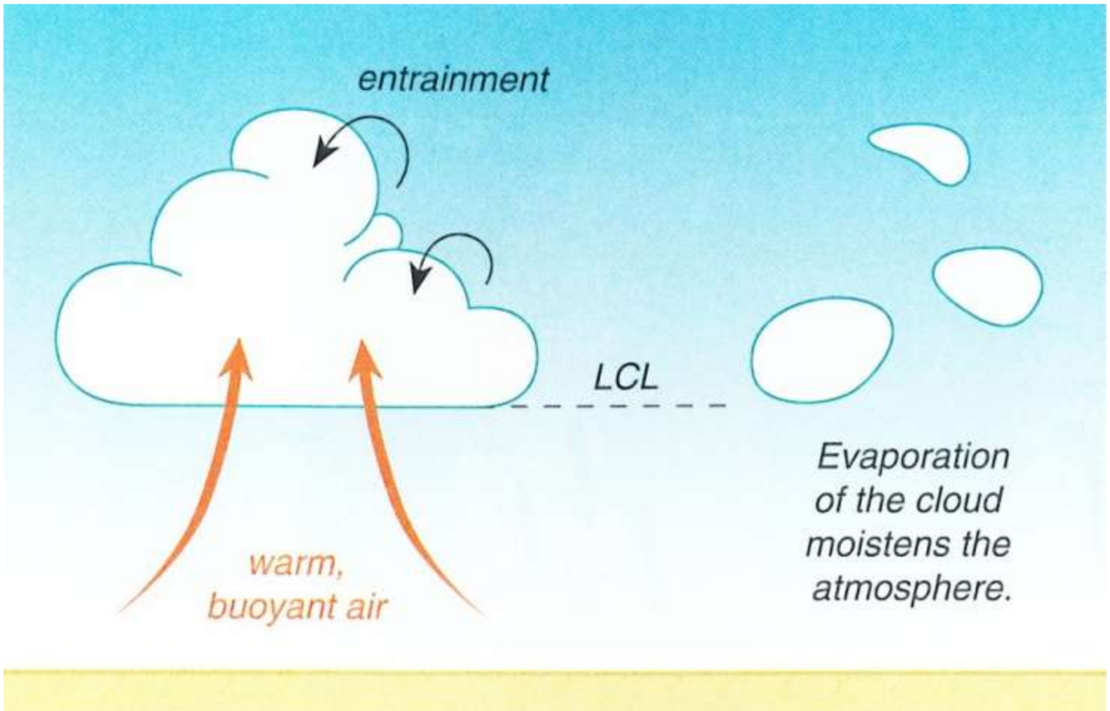
Stability is something we dealt with in the adiabatic rates. The question of stable and unstable air should be clear (hopefully) but the chart indicates greater and greater instability which simply is the degree of instability.

The Lift index is calculated combining average humidity in the lower atmosphere, the predicted high temperature and the temperature at the 500 mb level into a single number. The magnitude and sign of the number indicate the potential for thunderstorms. The negative values indicate sufficient water vapor and instability to trigger thunderstorms.

AIR MASS THUNDERSTORMS

These are the most common, the least destructive and usually last less than an hour.

Thunderstorms are usually preceded by the formation of one or several cumulus clouds that grow and break down (dissipate) and put moisture in the air. This sets the stage for storm development.



Convection causes turbulence and very moist air parcels which bound the cloud are constantly being mixed with the drier around surrounding them. THE MIXING OF CLOUD PARCELS WITH DRY AIR IS CALLED "ENTRAINMENT". The dry air lowers the dew point temp and causes some evaporation of the droplets. So moisture has been moved into the air by convection and increased the Relative Humidity.

Although the first forming clouds may dissipate they have moistened the air which reduces the amount of evaporation in the next cloud. In summer the sequence often involves larger and large clouds forming through the afternoon as the ground warms.

At some point, the cloud might become tall enough that collision and coalescence of cloud droplets within the cloud start to produce precipitation

The process occurs quickly and produces concentrated and sometimes heavy showers. IF THE CLOUD REACHES ALTITUDES WHERE TEMPERATURES ARE BELOW -10^0C ice crystals form which become critical in the physical process to produce lightning (MORE LATER)

If the thunderstorm develops, it goes through stages: the Cumulus stage, the Mature Stage and the Dissipating stage

Mild convection causes rising unstable air (adiabatic) (no heat added or removed) which produces fair weather cumulus clouds. These grow upward at about 20m/sec (10 to 45 mph). If they are lifted to the "lifting condensation level" the point where their temperature drops below the dew point temperature, condensation happens and cloud droplets appear. In unstable air continued convection can produce tall cumuliform clouds along with hail and rain in heavy showers. When the wind shear is weak, (the change in wind speed with altitude) "ORDINARY STORMS" or AIR MASS STORMS develop. These are not severe weather but exceptions can occur in EXTREMELY UNSTABLE AIR. (If the wind shear is significant highly organized storms can develop which can take the form of "super cells" or "squall lines" - a line of thunderstorms associated with an advancing front).

MATURE STAGE

This is the most vigorous time of the thunderstorm – precipitation, lightning and thunder are most intense. These storms are often MULTICELLULAR with cells located in DIFFERENT PARTS OF THE CLOUD which have formed at different times.

The top of the cloud reaches an altitude where STABLE CONDITIONS STOP THE UPWARD FLOW. STRONG HIGH LEVEL WINDS FORCE THE ICE CCRYSTALS AT THE TOP OF THE CLOUD FORWARD AND THE ANVIL SHAPE STARTS TO FORM.

As the mature stage begins precipitation starts to fall as heavy rain or graupel. This tends to move the air down with it and DOWN DRAFTS form where the precipitation is most intense. The downdrafts gain in strength from the cooling of the air as the precipitation evaporates. The air cools (giving up heat to evaporate the water) and becomes heavier and increases the down drafts. Most of the water in the cloud about 80% does NOT fall as precipitation but evaporates out of the cloud.

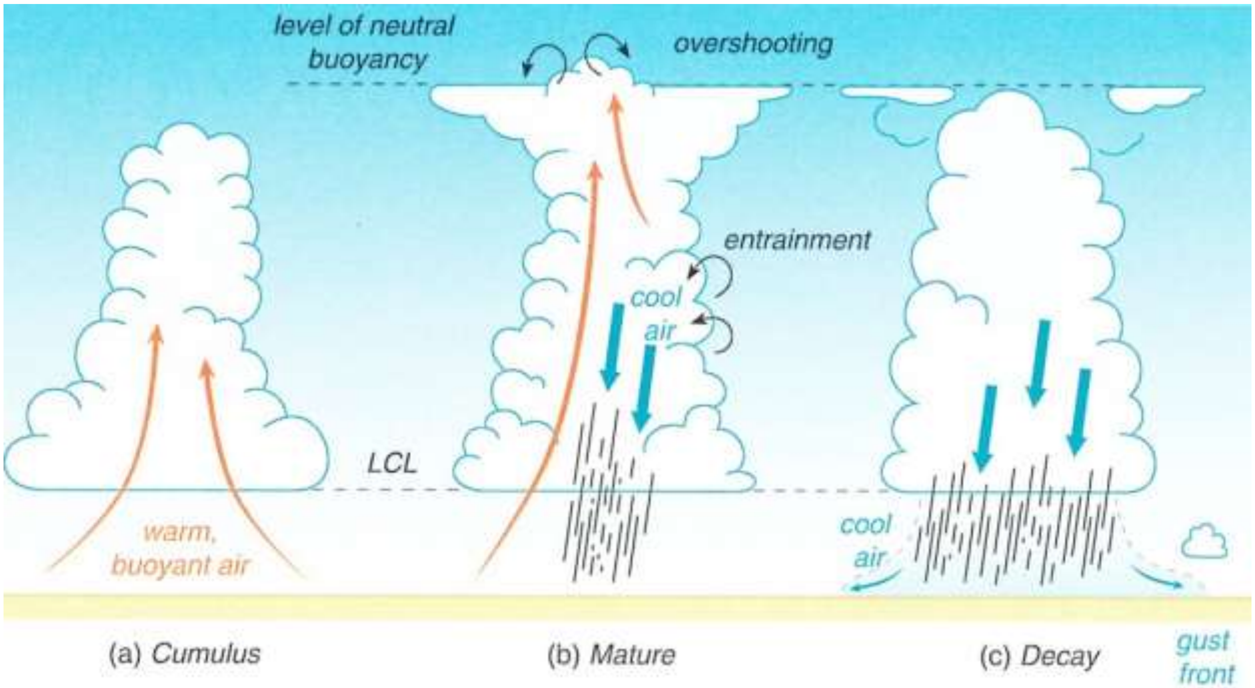
DISSIPATIVE STAGE

In the DISSIPATIVE STAGE, the heavy precipitation causes the downdrafts become stringer and occupy more and more of the cloud until the entire base of the cloud is covered with downdrafts.

When the cumulus cloud reaches the stratosphere it flattens out against the stable air there (temp inversion blocks further upward movement). The cloud becomes a cumulonimbus with the flattened “anvil shaped” top.

Precipitation falls into the unsaturated air below and evaporates. Because this requires latent hear, the heat is taken from the environment and there is a cooling effect. The cooler air sinks back to the surface under the cloud making cool downdrafts. These compete with the convective updrafts. Friction between the falling drops and the surrounding air also enhances the downdrafts.

At the surface a cold pool forms – which is the sinking cold air. This spreads outwards creating a gust of cold wind which is often felt in the vicinity of a thunderstorm. Since these often happen in the late afternoon the difference in temperature between the cold air and the surrounding warm is often significant. The boundary between the outward moving cold air and the surrounding warmer air produces a GUST FRONT which as usual, the colder air pushes under the lighter warmer air forcing upward motion which forms more small clouds which can develop into their own storms. It is not uncommon for thunderstorms to spawn more thunderstorms in this way.



SEVERE THUNDERSTORMS - MULTICELL

Multicell thunderstorms are made up of several individual single cell storms each at a different stage of development – some forming some mature and some dissipating.

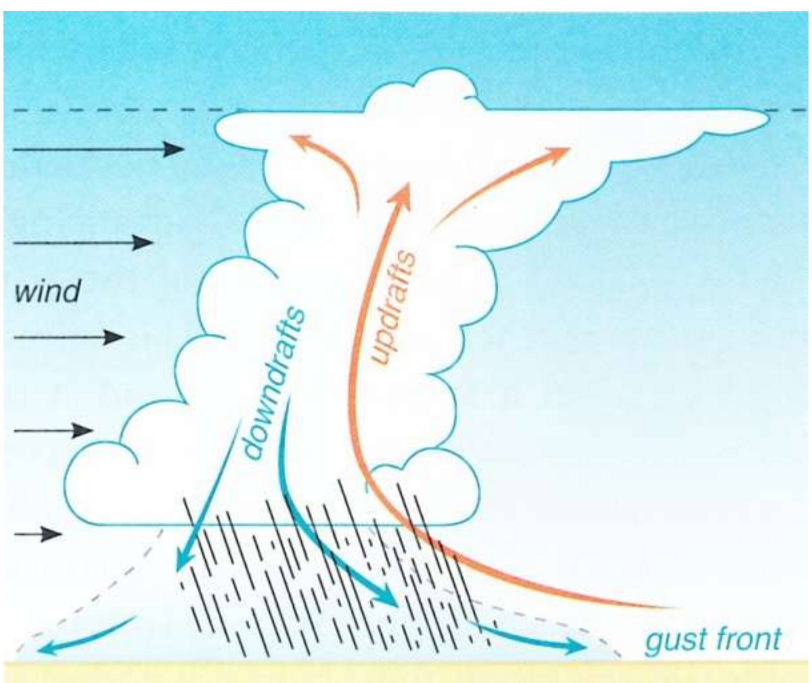
These storms have wind speeds of at least 93 km/hr (58 mph); hailstones larger than 1.9 cm (0.75 inch) or spawn tornadoes. Downdrafts and up drafts in severe thunderstorms reinforce one another. Suitable conditions for this require a fairly large area – 10-1000 km 6-600 miles (making these mesoscale storms) with wind temperature and humidity all “cooperating”. Because the area is so large these severe storms often appear in groups or clusters and are referred to as MESOSCALE CONVECTIVE SYSTEMS (MCSs). They may occur in linear bands called SQUALL LINES”. Other times they may occur in roughly circular or oval arrangements called MESOSCALE CONVECTION COMPLEXES (MCCs). The arrangement is immaterial because the storm cells form as a part of a single system – they are not just storms that happen to be close together.

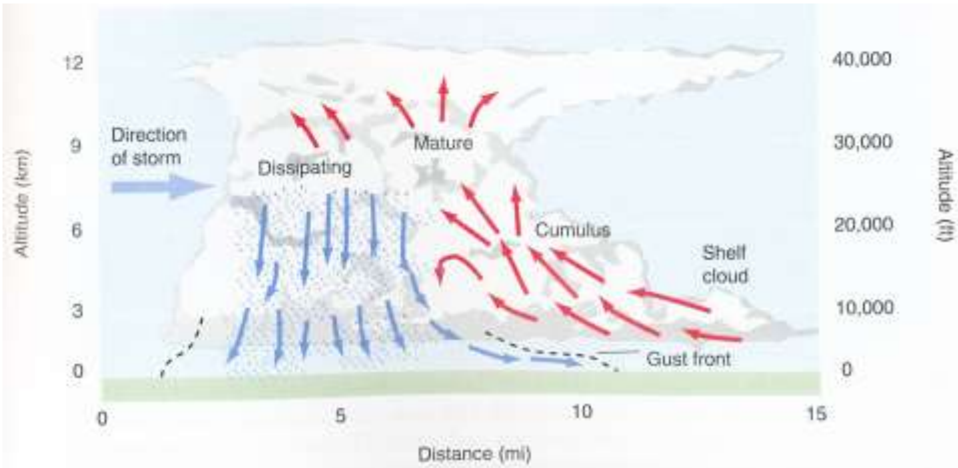
These storms can cover several counties and may last typically as long as 12 hours although in some cases they have persisted for days. Common in central US and Canada, they account for about 60% of the rainfall in those areas.

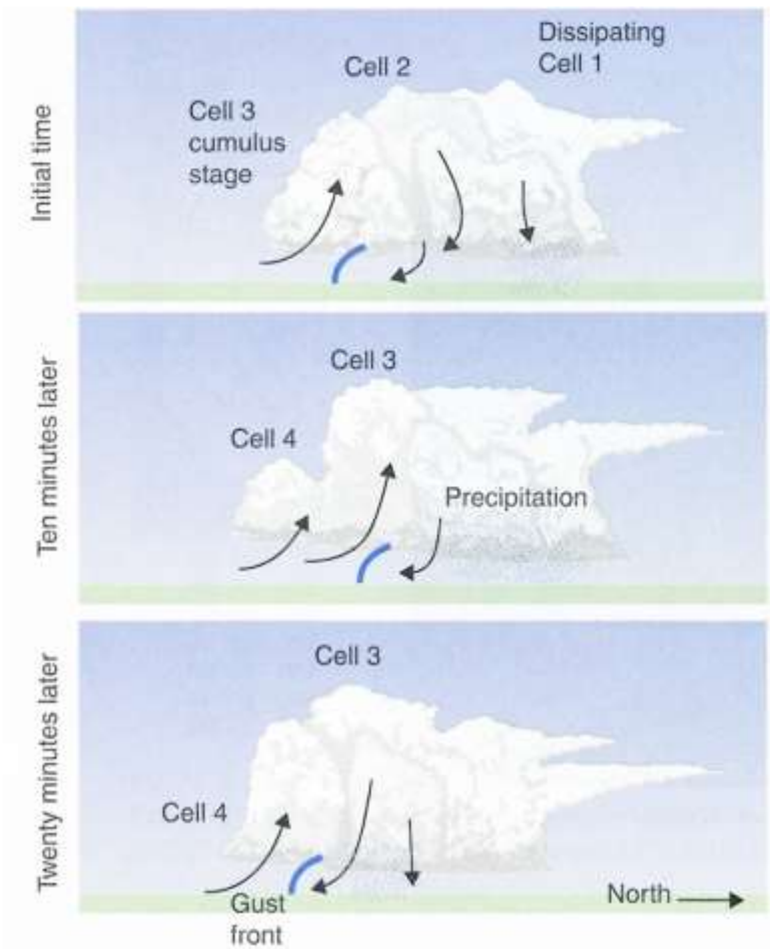
Severe storms can also arise from SUPERCELLS – VERY powerful storms that contain a single updraft zone. Supercells may occur in isolation, but also in a Mesoscale Convective System

SEVERE THUNDERSTORMS require wind shear, high water vapor content in the lower troposphere, something to trigger uplift and

This happens on the southern Great Plains in the spring and summer when warm surface air from the Gulf of Mexico in the middle troposphere while westerly winds bring dry air from the southern Rockies underneath the warm. BUT given sufficient uplift, the surface air can become statically unstable and severe storms can develop







SQUALL LINE THUNDERSTORMS

These require the presence of WIND SHEAR

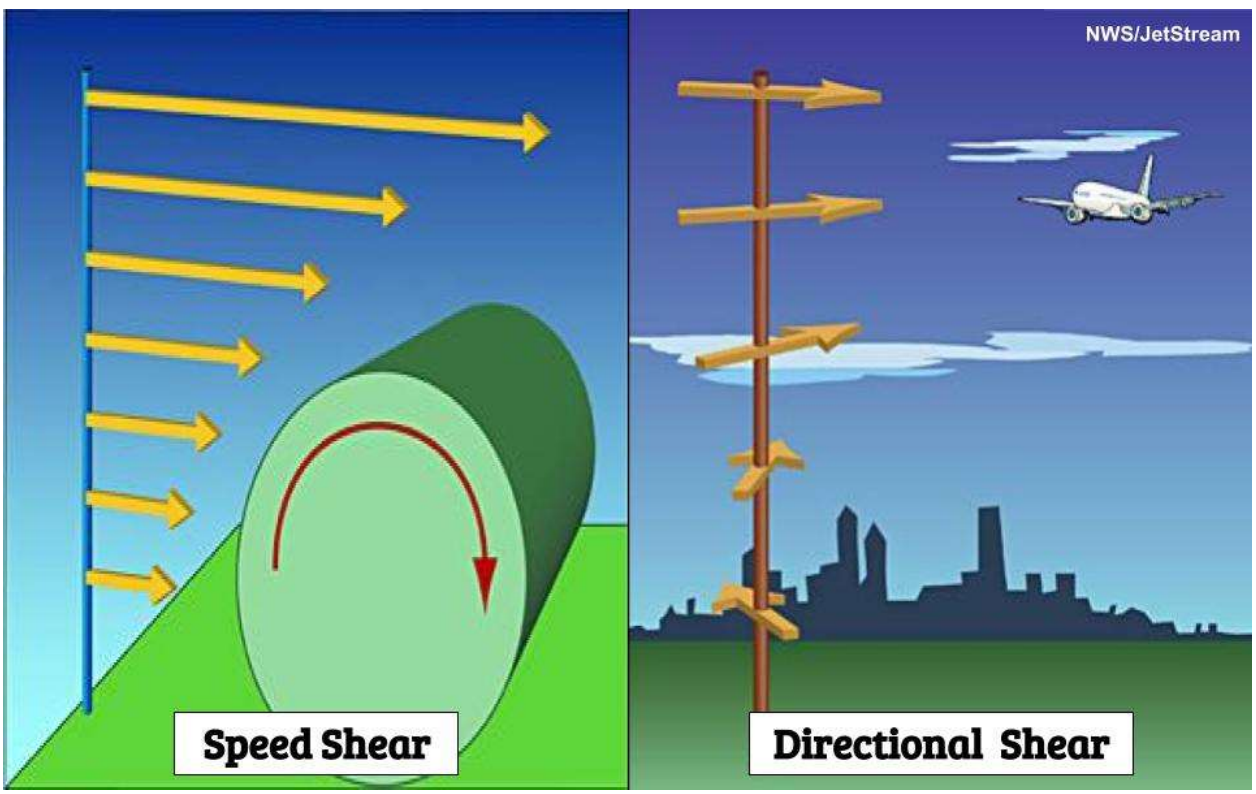
WIND SHEAR AGAIN

Wind shear can be horizontal or vertical

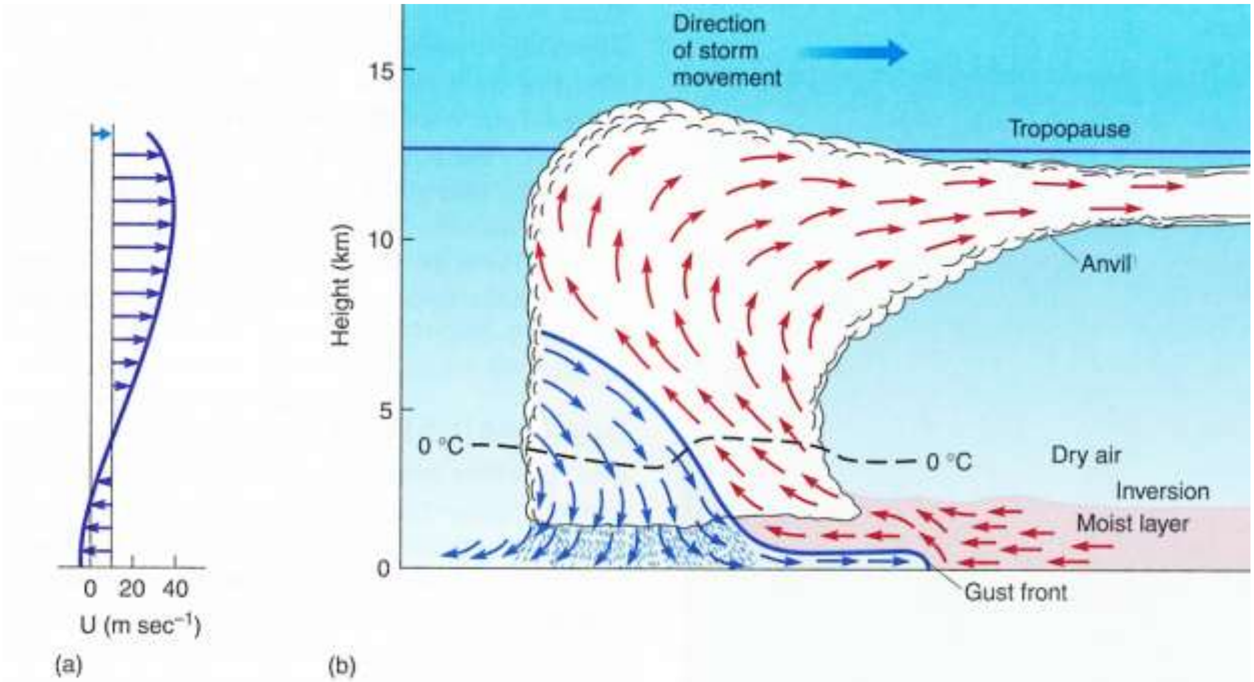
Vertical wind shear occurs when winds moving horizontally (but arranged vertically – that is one over the other) move at different speed creating the "shear"

Horizontal wind shear occurs between two masses of air next to one another (that is one is to the right or left of the other hence horizontal to one another) moving at different speeds or in opposite directions cause "shear"

The shear can be caused by a change in speed between two layers or by change of direction between neighboring levels or both.

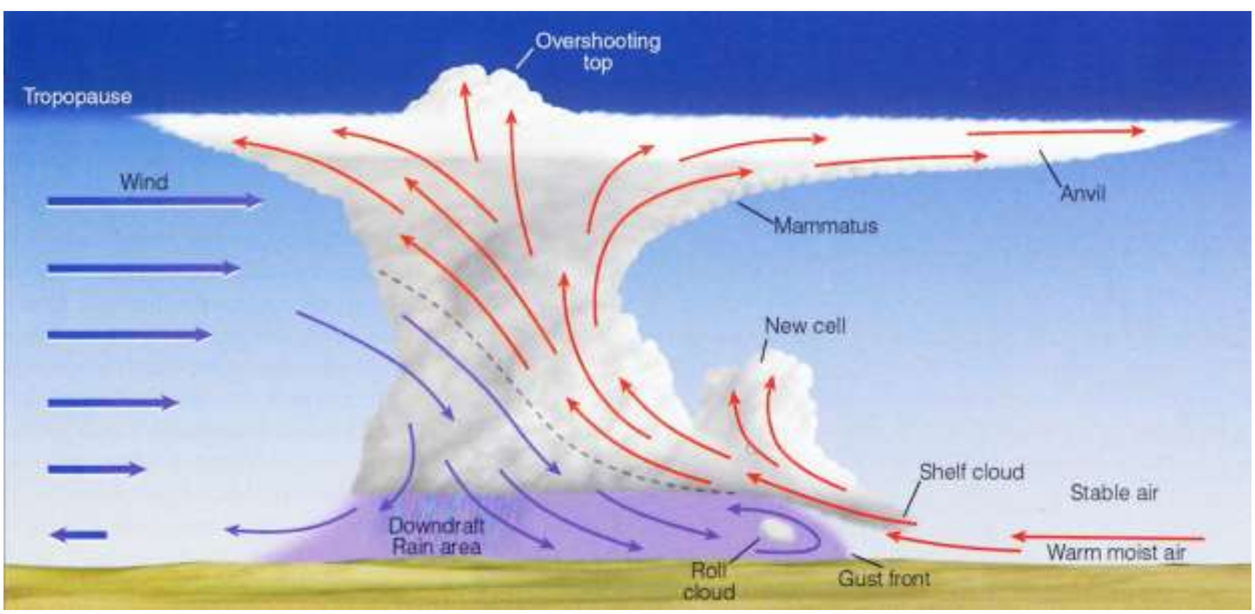


A squall line is composed of individual intense thunderstorm cells arranged in a line or band.



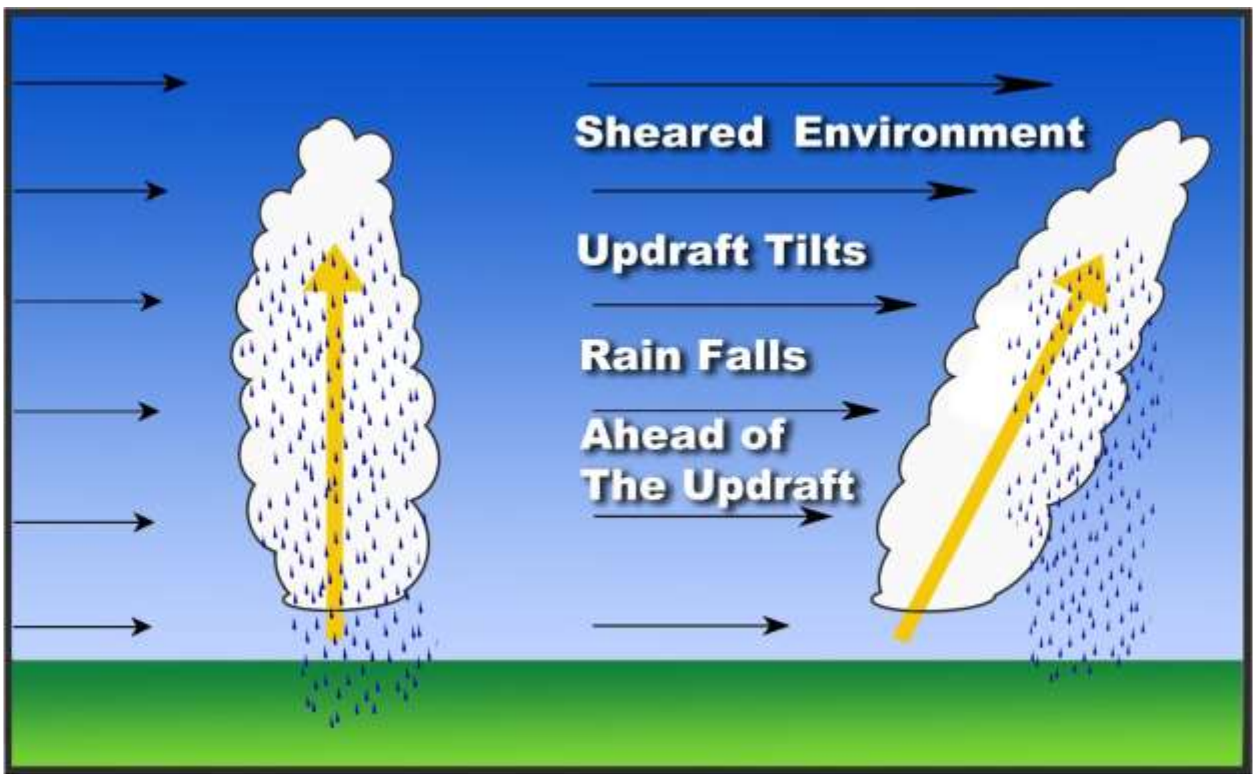
In this view (above) the moist air being plowed under moves upward into winds which are moving in the opposite direction

Cold air drawn in from the rear moves in and down into winds in the opposite direction (so there is vertical shear – winds above move to the front, winds below move to the rear) which causes the tilt.



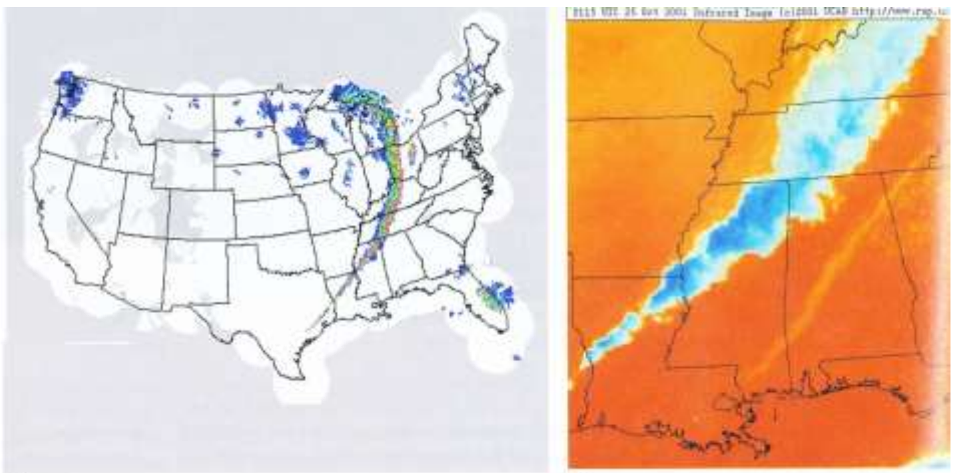
Note the parts of the cloud. Near the ground there is a moist layer of air and above it a dry layer (inversion – dry air is heavier than moist air). At the top, which presses against the tropopause, an “anvil” cloud stretches out ahead of the main storm. Near the ground a cold front slides under a moist layer of air forcing the warm moist air upward. Just above is a shelf cloud. Down rushing air produces a GUST FRONT with a roll cloud.

Air drawn in from the rear moves in toward the updraft but the shear keeps them separate and cold wind descends and warm air rises. The tilt helps keep them separate so the downdrafts don’t terminate the storm the way they is in air mass thunderstorms.



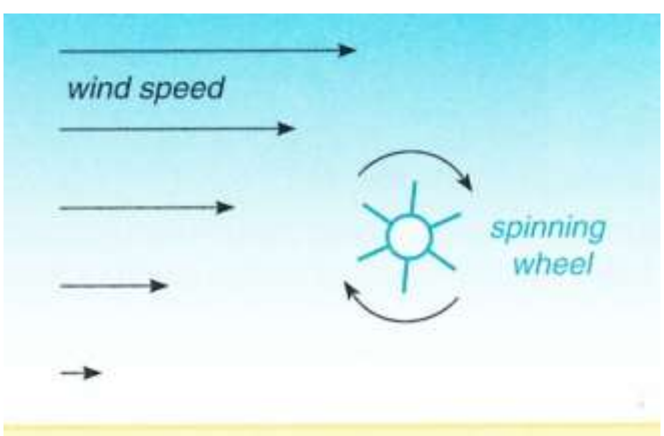
Rising air along the frontal boundary (and along the gust front) coupled with the tilted nature of the up draft promotes the development of “new cells” as the storm moves along. Old cells decay and dry out while new ones constantly form and the squall line can maintain itself for hours.

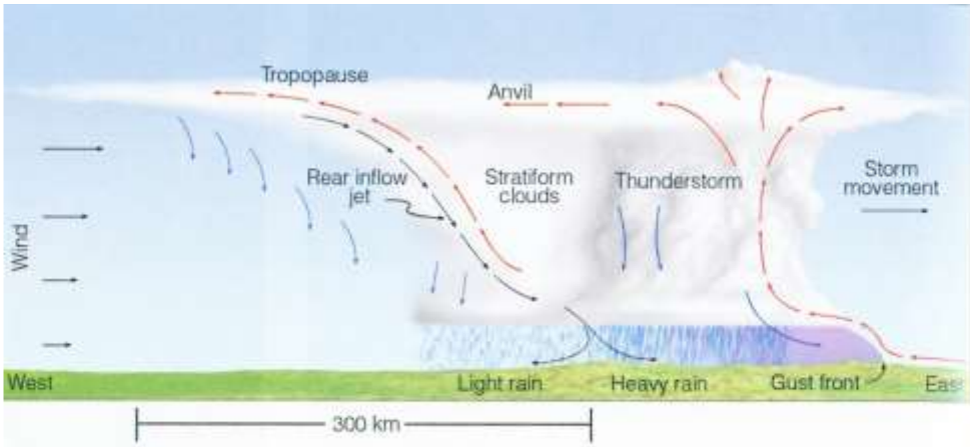
This occurs along a boundary of unstable air which causes them to have a linear appearance. They usually last 6-12 hours and the line may extend across several states.


(a) (b)

Clouds sometimes form above the gust front called “shelf clouds”. They are caused by the gust front forcing under the warm air ahead of it. They look ominous but do not produce damaging weather themselves.

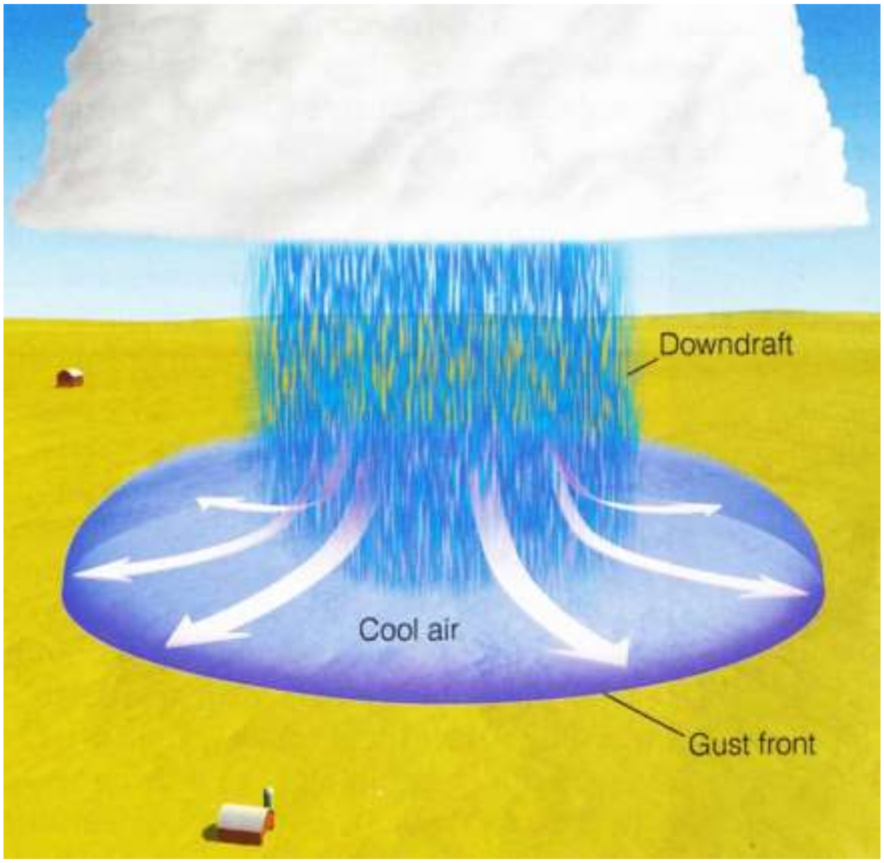
Sometimes elongated nasty looking clouds form just behind the gust front which seem to spin slowly about a horizontal axis (roll clouds)





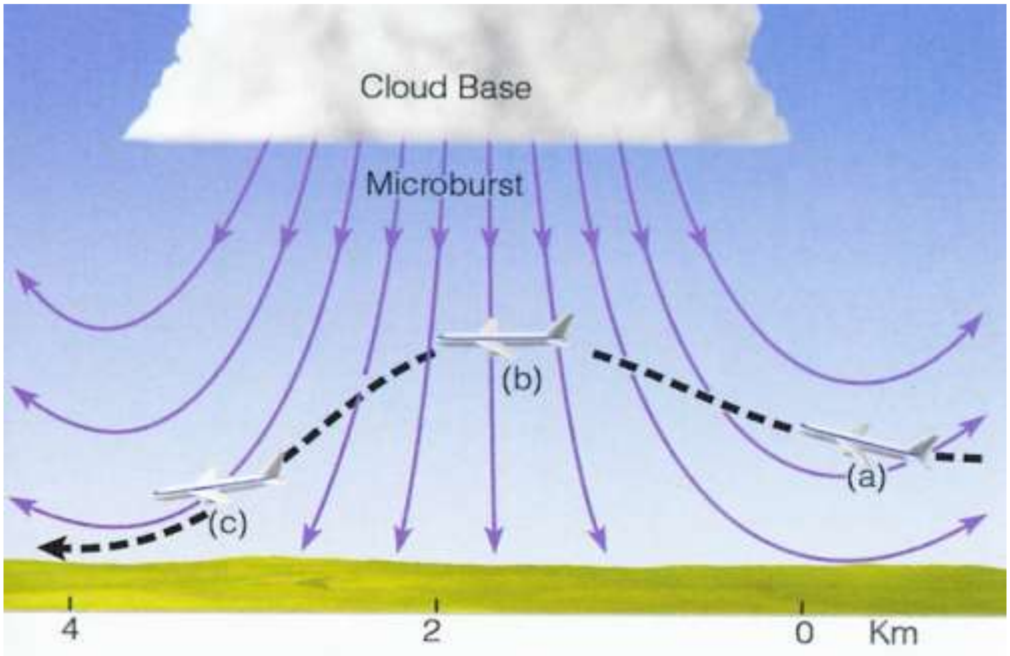
MICROBURSTS

Beneath an intense thunderstorm, the downdraft may become localized so it strikes the ground spreading out horizontally. A downdraft with winds extending 4km or less is called a “microburst” (large ones are called macrobursts)



The gust produced can be extremely fast as high as 146 knots (168 mph or 270 km/hour). Microbursts may be responsible for some damage thought to have been caused by tornadoes.

They are extremely dangerous to aircraft:



The answer is at (a) the plane begins to climb (it gains lift) If the pilot corrects by bringing the nose down, within seconds the plane will be being forced down by the powerful downdraft at (b) and then gets a tail wind at (c) with a sudden loss of lift and decrease in performance of the aircraft which is now headed toward the ground.

Usually they are cold but can be hot (heat bursts). These are thought to originate high in the storm and warm by compressional heating as it rushes downwards. One occurred in Chickasha Oklahoma May 22 1996 which raised the temperature from 88F to 102 in 25 minutes!

These microbursts can occur with ordinary thunderstorms as well as these severe ones.

SUPERCELLS

These occur in regions where there is strong vertical wind shear in both speed and direction. The thunderstorm may form in such a way that the cold outflow of air never undercuts the updraft. The shear may be so strong that it creates a horizontal spin which if tilted into the updraft causes the column of rotating air itself to rotate to a more vertical position. A LARGE LONG LASTING THUNDERSTORM WITH A SINGLE VIOLENTLY ROTATING UPDRAFT IS CALLED A SUPER CELL. The rotation is what leads to the formation of tornadoes.

The storm may maintain itself AS A SINGLE ENTITY for hours. Updrafts may appear in excess of 90 knots. There are damaging surface winds and tornadoes possible.

Updrafts are strong enough to keep hailstones in the cloud until they may reach grapefruit size when they either fall out of the bottom of the cloud with the downdraft or the internal rotation may throw them out of the side of the cloud. Planes have been hit by hailstones thrown from a super cell several kilometers from the storm!

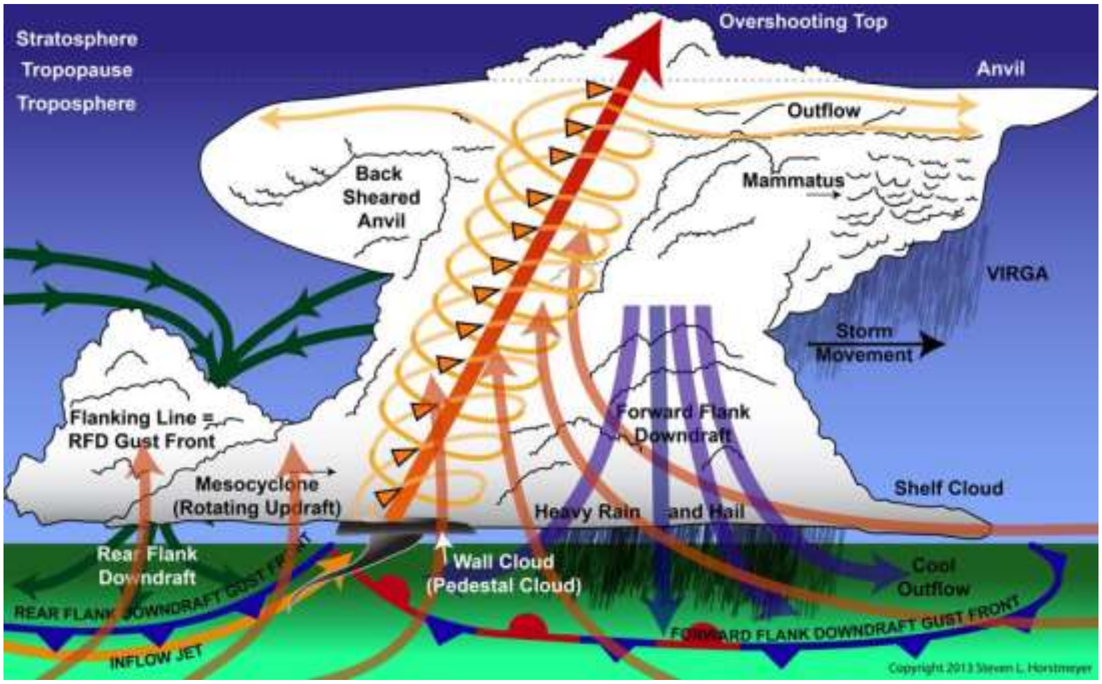
The storms may rise upwards of 18 km (60,000 feet) and be larger than 45 km (25 miles) wide

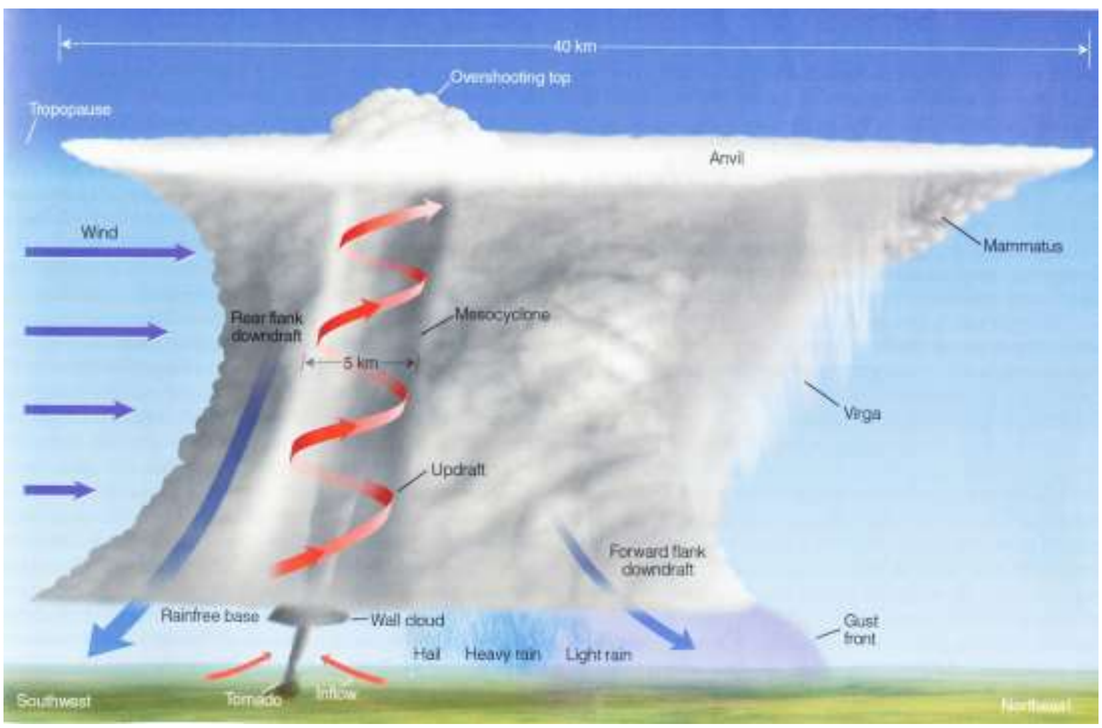
Three kinds of supercells are found: Classic (CL); HP supercells (high precipitation supercells) and LP supercells (Low precipitation supercells).

Classics produce heavy rain, large hail, high surface winds, and the majority of tornadoes.

HP Supercells produce heavy precipitation, large hail that seems to fall from the center of the storm, extreme downdrafts (downbursts) and flash flooding. If a tornado forms it is hard to see it since it forms in the area of heavy precipitation.

LP supercells have little precipitation. They produce tornadoes, large hail and have a “corkscrew appearance”.



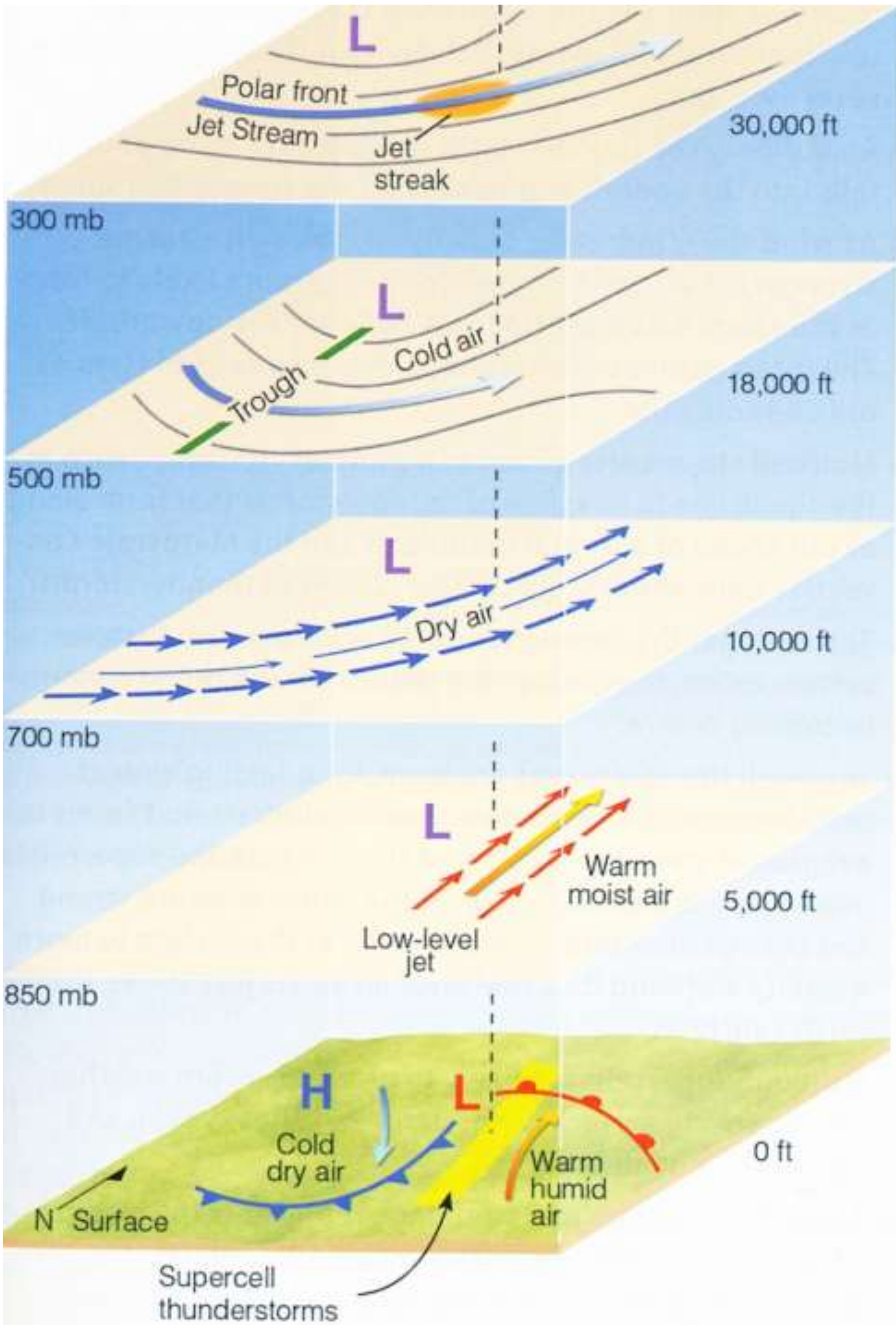


In the image the rotating column of air is 5-10 kilometers across and is called a "mesocyclone" i.e. mesoscale cyclone). The rotation is so strong that precipitation can't fall through it. This produces a "rain free base" beneath the updraft. Strong SW winds blow the precipitation to the NE. Large hail falls just N of the updraft and the heaviest rain just north of the falling hail. Lighter rain falls in the NE quadrant.

If low level humid air is drawn up into the updraft, a rotating cloud, a WALL CLOUD, may appear from the base.

WIND SHEAR AND THE SUPERCELL:

This represents the spring in the central plains. . There is at the surface an open wave middle level cyclone with cold dry air moving in behind a cold front and warm humid air pushing in from the Gulf of Mexico behind a warm front.



Above the surface map at 5,000 feet (850 mb) there is a wedge of warm moist air streaming northward. This is the "low level jet". It often is faster than 50 knots.

At 700 mb (10,000) is a wedge of cooler drier air from the SW

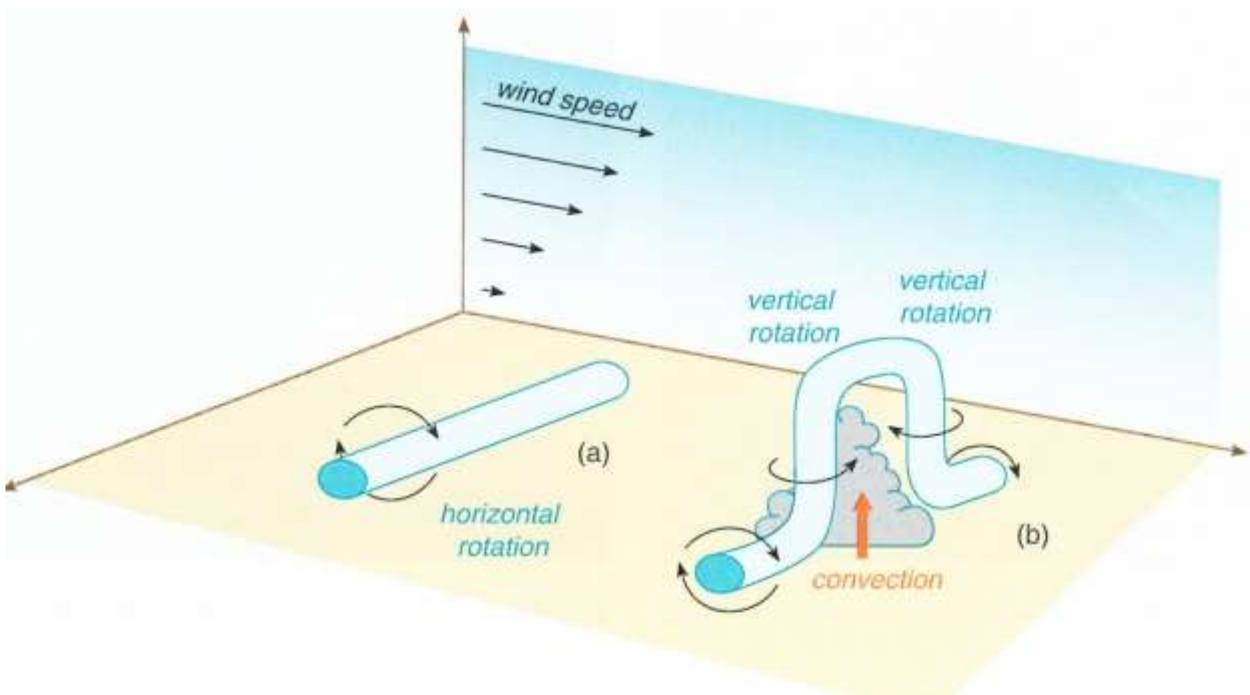
Still further up at 500mb (18,000 feet) a trough of low pressure exists to the left of the surface low.

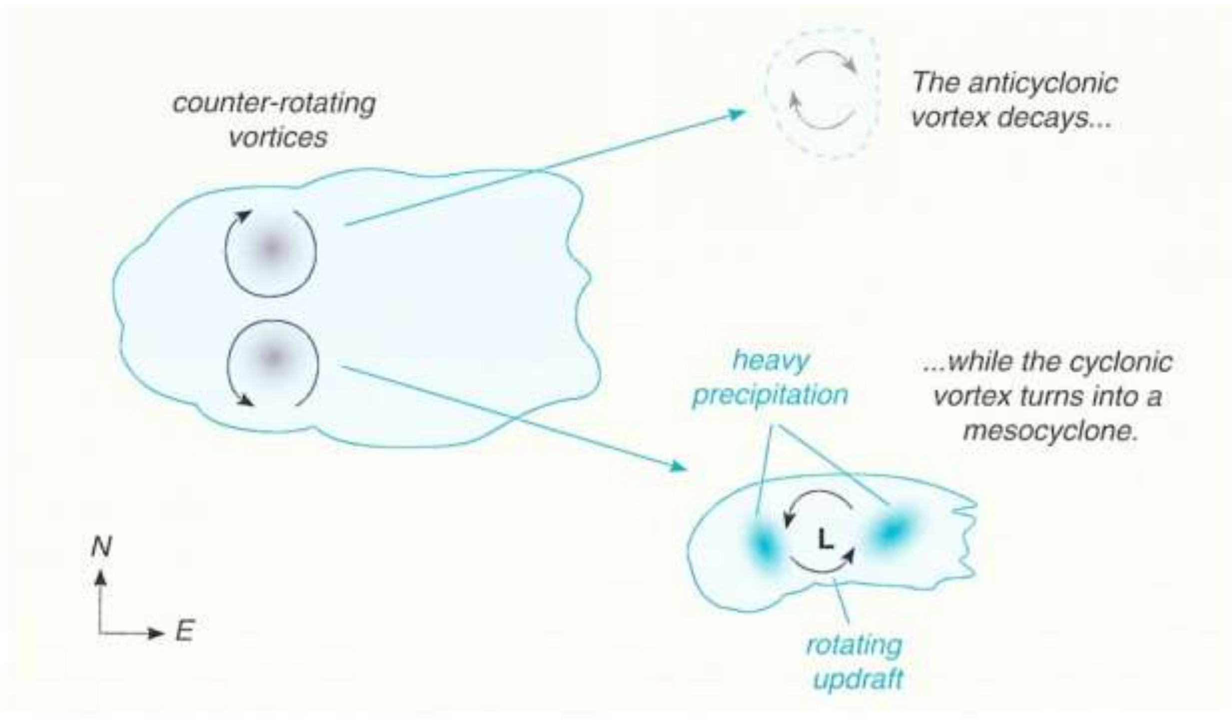
At the 300 mb (30,000 ft.) level, the polar jet appears with a jet streak (maximum wind) above the surface low.

At the surface one can see where the yellowish line is, the area where the supercell thunderstorms are likely to form. They tend to form here because (the position of the cold air above the warm are produces conditionally unstable atmosphere and because (2) there is strong vertical wind shear

Rapidly moving air up to the level of the low level jet provides strong vertical shear which induces rotation.

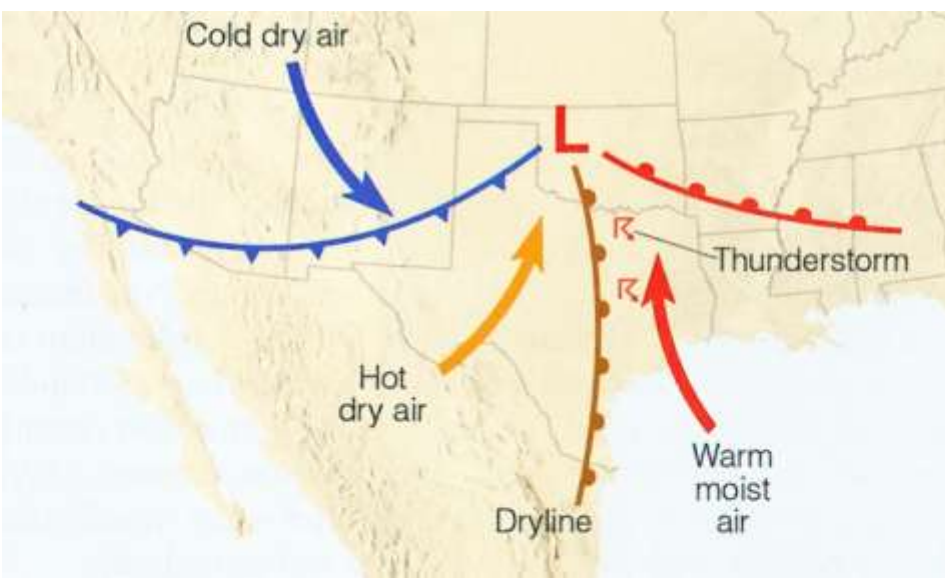
Strong vertical wind shear causes air to spin around its horizontal axis. (TRY IT WITH A PENCIL)





DRYLINES

Dry lines (which are areas that are narrow boundaries between areas where there is a step horizontal change in moisture). They separate moist air from dry air. Dew points may vary by 16 degrees F and so they are sometimes called dew point fronts)



Here warm moist air from the polar region (cP) is moving in behind the cold front. In the warm air ahead of the cold front is hot dry continental tropical air (cT). To the east is warm very humid mT air moving N from the Gulf of Mexico. The dryline is the N/S line that separates warm dry air from warm moist air.

The cold air moves in to replace the hot dry air, but there is insufficient moisture for thunderstorms. The moisture boundary is along the dry line. The plains slope down to the east and so the hot dry air is able to ride over the slightly cooler moist air from the gulf. This can lead to rising air and the development of thunderstorms. As they form the cold gust front may move along the ground and trigger more severe thunderstorms.

Briefly

FORMATION

Four ingredients known as shear, lift, instability and moisture – SLIM, for short – come together in an area known collectively as Tornado Alley and Dixie Alley better than anywhere else in the world.

Shear – wind shear, as it pertains to severe weather, is the change of wind speed over a distance.

Two different types of wind shear are necessary for tornadogenesis: changes in wind *speed*and/or wind *direction* with height.

Lift – the faster air can rise, the more severe a storm can become.

A few sources of lift include cold fronts, warm fronts, dry lines, sea breezes and mountain ranges. Each of these forces air upward and boosts storms' ability to grow taller and stronger.

The main source of this lift is a change in density. For instance, in a cold front, the cold air is wedged under warm air because cold air is denser. As cold air shoves its way east or south under the warm air ahead of it, that warm air is forced to rise. This usually helps stimulate thunderstorms and can help strong storms reach severe limits.

A stronger cold front will have the densest air behind it, so it will have more associated lift, as compared to a weaker front.

Outflow boundaries, gusts of cooler air that come from deep within a storm, can also collide with other thunderstorms or their remnants and create sources of lift.

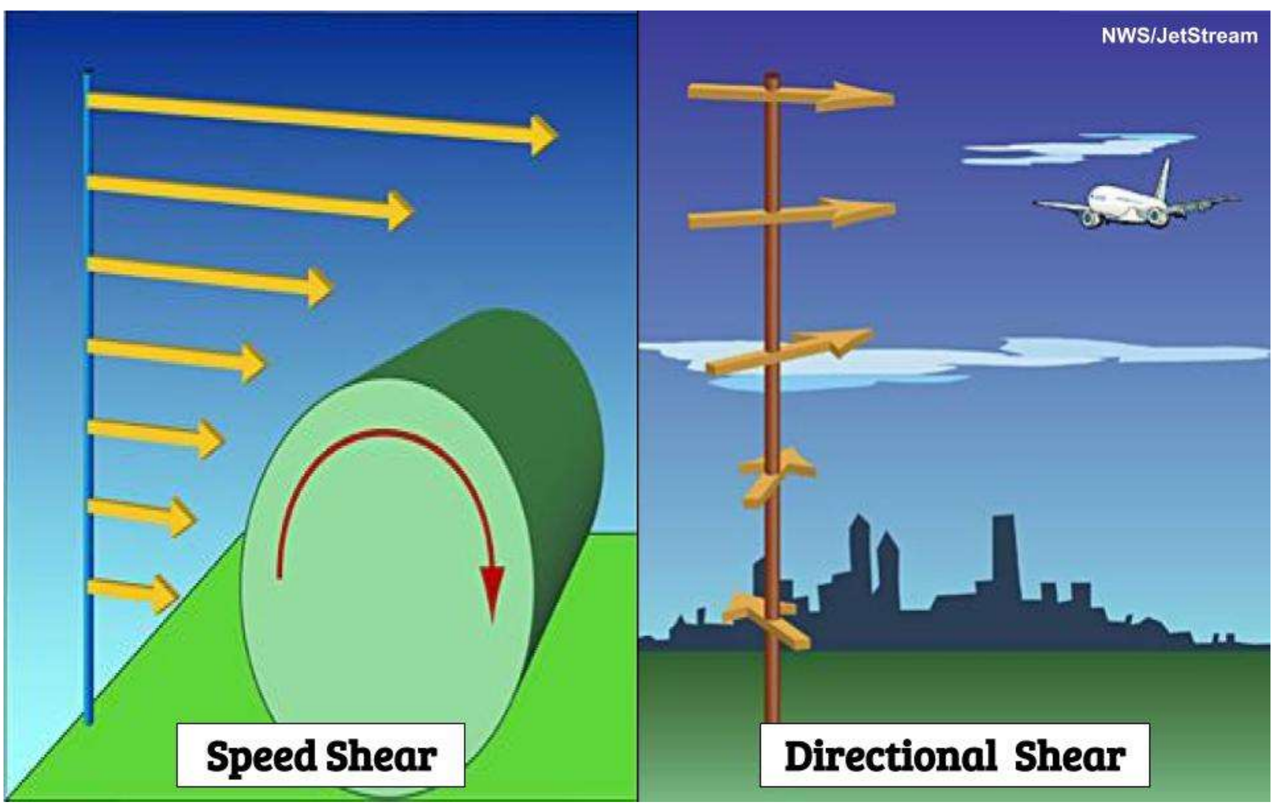
Instability – the condition that air is freely available to move upward into the atmosphere. If the atmosphere where clouds are trying to grow is stable, then those clouds will be "capped" or unable to grow. The atmosphere is stable when the temperature warms as height increases.

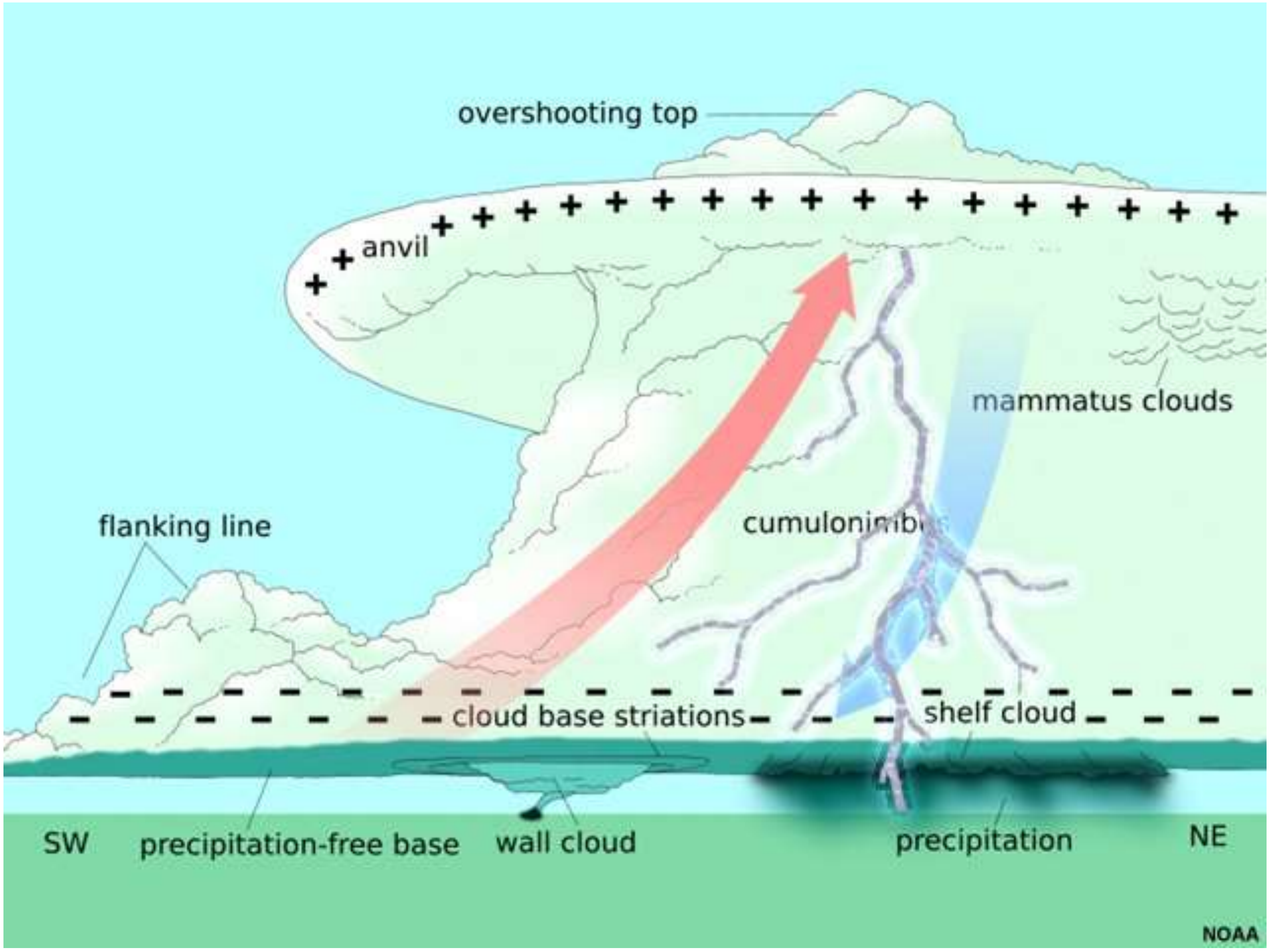
In many winter and even some spring situations, instability is usually the factor that limits storm systems from producing larger severe weather outbreaks, due to a lack of heat.

Another situation where instability can be inhibited is when cloud cover spreads over a region. Clouds limit the amount of heat that can reach the ground and fuel thunderstorms.

Moisture – The more moisture that is available for storms to take root, the more buoyant their environment will be and the more they can grow.

The Gulf of Mexico is very well positioned as a moisture feed. During the springtime months, most low-pressure systems swing from the Rockies across the South. Ahead of these systems, deep southerly winds scoop up moisture from the Gulf and bring it northward in the perfect spot for severe weather, including tornadoes.





TORNADOES

Definition: A tornado is a rapidly rotating column of air extending down from a cumiliform cloud that blows around a small area of intense low pressure with a circulation that reaches to the ground. It appears as a funnel shaped cloud or as a swirling cloud of dust and debris. They are called cyclones or twisters. They are shaped like twisting rope funnels, cylindrical shaped funnels to those that look like an elephant's trunk hanging from a large cumulonimbus cloud. (One article says that is why the rain god in Mexico has a trunk) A FUNNEL CLOUD is a forming tornado that has not reached the ground. About 30% of these may become active tornadoes.

Tornadoes tend to rotate counterclockwise but a small number have been recorded that go clockwise.

Wind speeds are usually less than 115 mph (100 knots) but some have speeds exceeding 220 knots (253 mph). Most are from 300 to 3000 feet wide, but some have exceeded a mile. One measured 2.5 miles across. The move forward at about 20-30 knots but some move as fast as 70. Some seem to have lasted for hours and cut paths 219 miles long.

Stage I Dust whirl. Dust swirls up from the surface. Short funnel goes from cloud base. Little damage

Stage II Organizing stage: Increase in intensity, with downward extent to funnel.

Stage III. Mature stage: (most severe damage) Greatest width and is almost vertical.

Stage IV: Shrinking stage: decrease in width, increase in tilt, narrowing of swath, but still capable of great damage

Stage V: Decay Stage: Stretched like rope. becomes contorted and finally dissipates.

Not all tornadoes go through all the stages. Some are skipped. If it reaches maturity it will stay on the ground until decay.

Most occur in US and about 70% of those are from March to July. May has the most on the average (about 9 a day). The most violent are in April when wind shear tends to be present as well as when horizontal and vertical temperature and moisture contrast are the greatest.

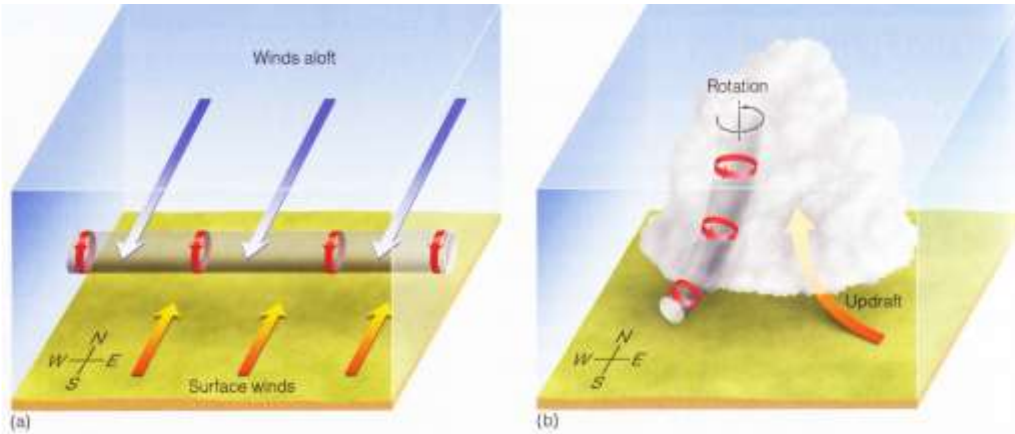
They are most frequent in the late afternoon but occur at all hours. They occur in all of the States except Alaska

Tornados are measured on the FUJITA and ENHANCED FUJITA SCALE. This measures the rotational wind speed. This was in the 1960's. Changes were made in 1971 which dal with damage done.

FORMATION

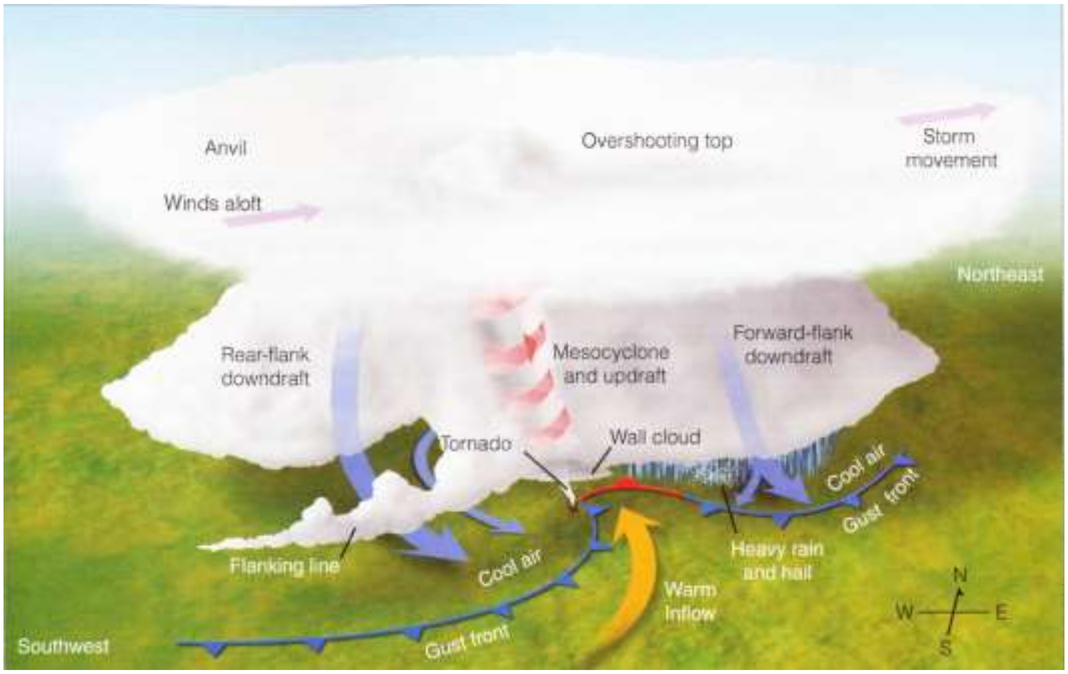
SUPERCELL TORNADOES

These are not unlike the rotation in the supercell itself in some ways.



The updraft in the tornado is very strong so there is no precipitation in it. If the mesocyclone persists, the can circulate precipitation around itself. This shows up on radar whereas the inside of the mesocyclone does not. The area where the radar does not detect anything is called a bounded weak echo region (BWER). The rotating precipitation may show up on the radar as a “hook echo”.

At this point the updraft, the counterclockwise swirling precipitation and the surrounding air may interact and produce a “Rear Flank downdraft”. This appears to play a large part in supercell tornados



When the rear flank downdraft his the ground it may interact with the front flank downdraft underneath the mesocyclone

At the surface of the mature supercell, the cool rain chilled air wraps around the updraft and the center of the mesocyclone initiating further spin.

The lower half of the updraft begins to rise more slowly than the updraft aloft. The updraft shrinks horizontally and expands vertically. This stretching of the spinning column of air increases its speed and finally becomes a tornado vortex

Air rushes up and spins around the low pressure core of the vortex and expands and cools and if moist enough condenses into a cloud. – The funnel cloud. As the air beneath is drawn into the core, the air cools rapidly and condenses and the funnel cloud descends to the surface where it picks up materials.

The Air along the outside of the cloud is spiraling upward, but Doppler radar reveals that within the core, the air is moving downward to extreme low pressure at the ground which is 100 mb less than the surrounding air.

Not all supercells produce tornadoes about 15% do.

Much of this is still unclear.

NON SUPER CELL TORNADOES

These form without the preexisting wall cloud or mid-level mesocyclone. They occur in multicell storms as well as with ordinary thunderstorms.

Some non-supercell tornadoes start on the ground and build up, while others start in the cloud and build down. The sometimes form along a gust front and are called GUSTNADOES. They are rather weak short lived and rarely cause damage.

Some occur from cumulus congestus clouds that are rapidly building. They seem to occur over central Colorado and look like waterspouts hence some people call them land spouts.

THUNDER AND LIGHTNING

Lightning is a discharge of electricity – a giant spark if you will. It may take place in the cloud or from the cloud to another cloud or from the cloud to the ground. The last accounts for about 20% of the lightning. The majority are within the cloud. Lightning heats the air to an incredible $54{,}000^0$ F or 5 times the temperature on the surface of the sun. This rapid heating causes the air to expand explosively in what is heard as thunder.

Because the light travels faster than the sound, you can estimate the distance of the strike. Sound travels about 1000 feet a second or 5 seconds to a mile. SO if there is a 15 second lapse between the flash and the thunder the strike was 3 miles away.

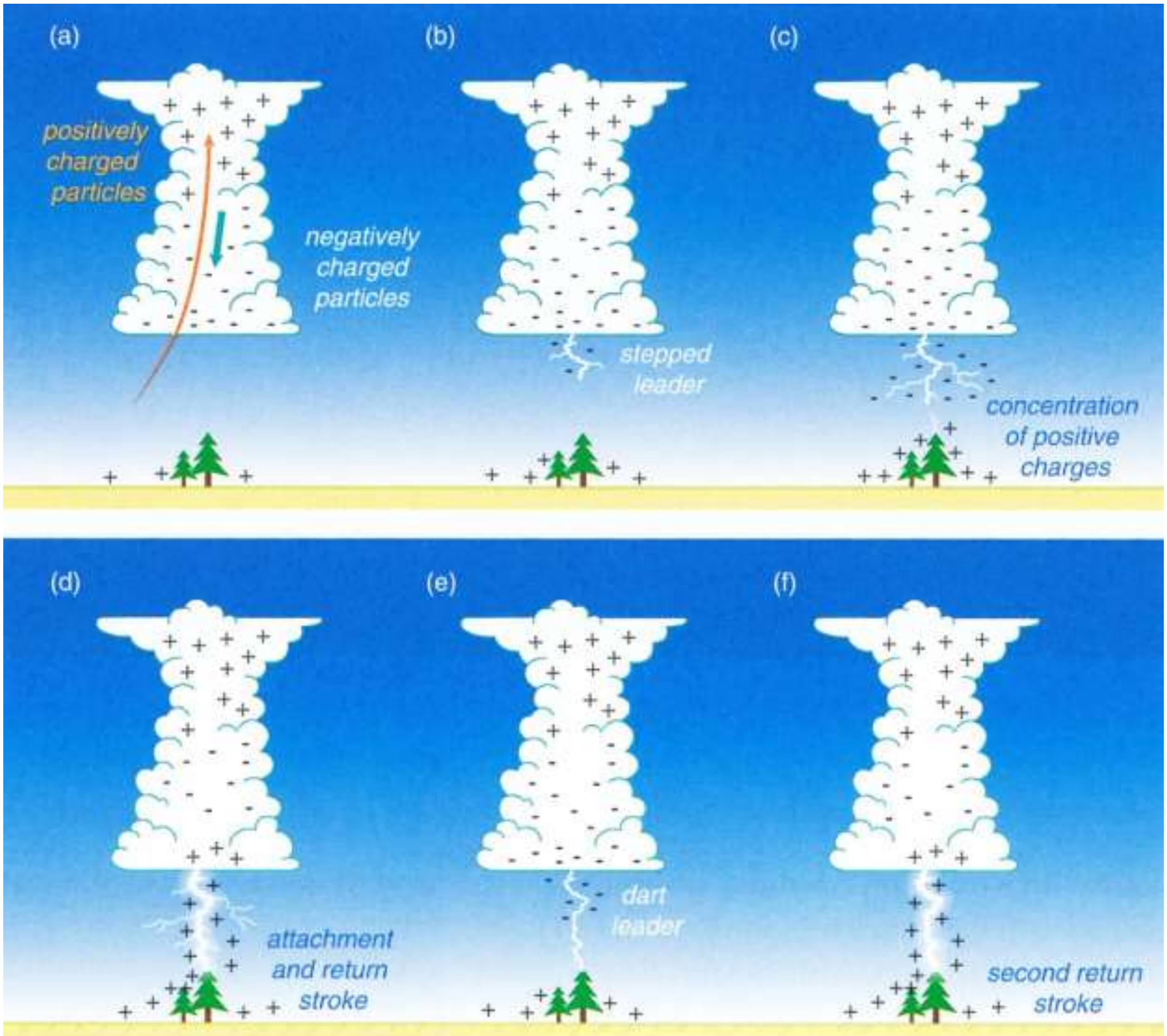
For lightning to occur separate regions containing opposite charged particles must exist in the cloud. How this happens is not understood although there are many theories. Some deal with hailstones becoming negatively charged. The result is an upper cloud layer being positively charged, a middle layer being negatively charged and the lower part being made if negative and mixed charges

The Stroke itself.

Because unlike charges attract, the negative underside of the cloud causes a region of the ground beneath to become positively charged. The positive charges follow the cloud along and tend to accumulate on protruding objects like trees poles and buildings. In dry air nothing happens because air is a good insulator.

As the gradient builds and reaches something like 1,000,000 volts per meter, the air's insulating properties break down, a current flows and lightning occurs.

Cloud to ground lightning begins within the cloud when the localized electrical potential gradient exceeds 3 million volts per meter along a path perhaps 50 meters long. The electrons in the cloud at that point rush to the cloud base and then toward the ground in a series of steps.



Each discharge covers 50 to 100 meters, the stops for 50 millionths of a second and then occurs again over another 50 meters. THIS STEPPED LEADER IS VERY FAINT and usually invisible to the human eye. As the tip of the stepped leader approaches the ground, the potential gradient (voltage per meter) increases and a current of POSITIVE CHARGE RUSHES UPWARD from the ground (usually from elevated objects). After they meet large numbers of electrons flow to the ground and A MUCH LARGER NUMBER AND MORE LUMINOUS RETURN STROKE SEVERAL CENTIMETERS IN DIAMETER SURGES UPWARD TO THE CLOUD ALONG THE PATH FOLLOWED BY THE STEP LEADER.

Lightning occurs in several forms. It is usually negatively charged, but positive charges occur and are more dangerous. There are various shapes like forked lightning, ribbon lightning (wind moves the channel making it look like a ribbon) bead lightning (like beads on string) ball lightning (a luminous sphere that appears to float in the air or slowly dart about for several seconds (it remains a mystery), sheet lightning (occurs in the cloud and the cloud glows while hiding the actual bolt)

HURRICANES

These storms come from warm tropical waters where there is a good supply of moisture. These storms pack a huge wallop in wind speed relative to area covered.

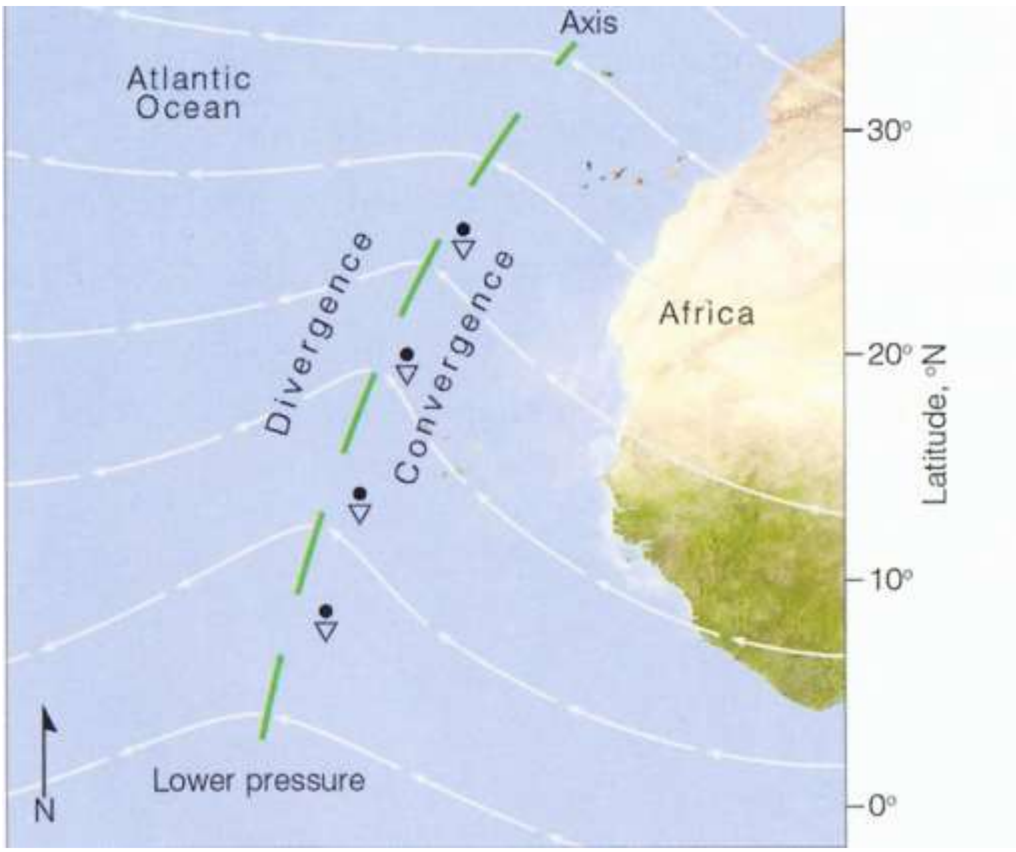
The Tropics and Tropical Weather

"The tropics" is the area between 23.5 N/S latitude. Sun is high diurnal and seasonal changes are small. Daily heating favors cumulus cloud development and afternoon thunderstorms which are mild. Sometimes they group into NON SQUALL CLUSTERS which are loosely organized. On some occasions however, they align into a row of strong convective cells known as a TROPICAL SQUALL CLUSTER or SQUALL LINE. As they pass there is a wind gust followed by an immediate downpour (as much as an inch in 30 minutes) and then several hours of steady rainfall. Many are like the mid latitude squall lines.

The tropics lack the 4 seasons which are marked by temperature variation. Seasons are often discussed in terms of PRECIPITATION. The greatest occurs in "high sun" conditions when the ITCZ moves into the region. Even in dry seasons the precipitation is irregular and it may rain for several days in a row.

Tropical winds tend to blow from the EAST, NE or SE. Changes in sea level barometric pressure is fairly small and drawing isobars is not particularly useful. Instead "STREAMLINES" that show the wind flow are used. They show where surface air converges and diverges. SOMETIMES THE STREAMLINES ARE DISTURBED BY A

WEAK TROUGH OF LOW PRESSURE CALLED A TROPICAL WAVE OR EASTERLY WAVE.



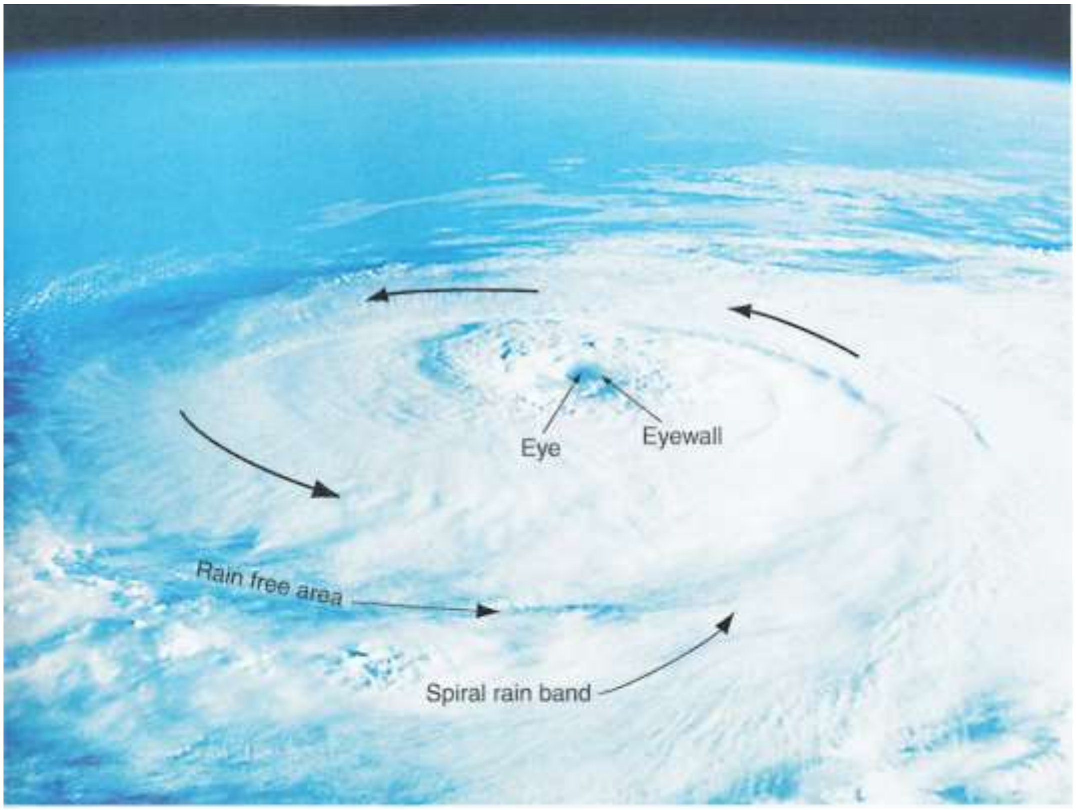
Tropical wavelengths are on the order of 2500 km (1550 miles) and travel westward at 10-20 knots.

On the western side of the trough easterly and NE winds diverge. Sinking air causes mostly fair weather.

On the eastern side of the trough SE, winds converge, rise and cool and often condense into showers and thunderstorms. The main area of showers is BEHIND the trough. Occasionally one of these will intensify and become a hurricane

ANATOMY

Hurricane: Intense tropical storm with winds 64 knots (74 mph) which forms over the warm N Atlantic and eastern N. Pacific. They are also known as “typhoons” in the western N Pacific, cyclones (India) tropical cyclones (Australia). Internationally they are known as “tropical cyclones”.



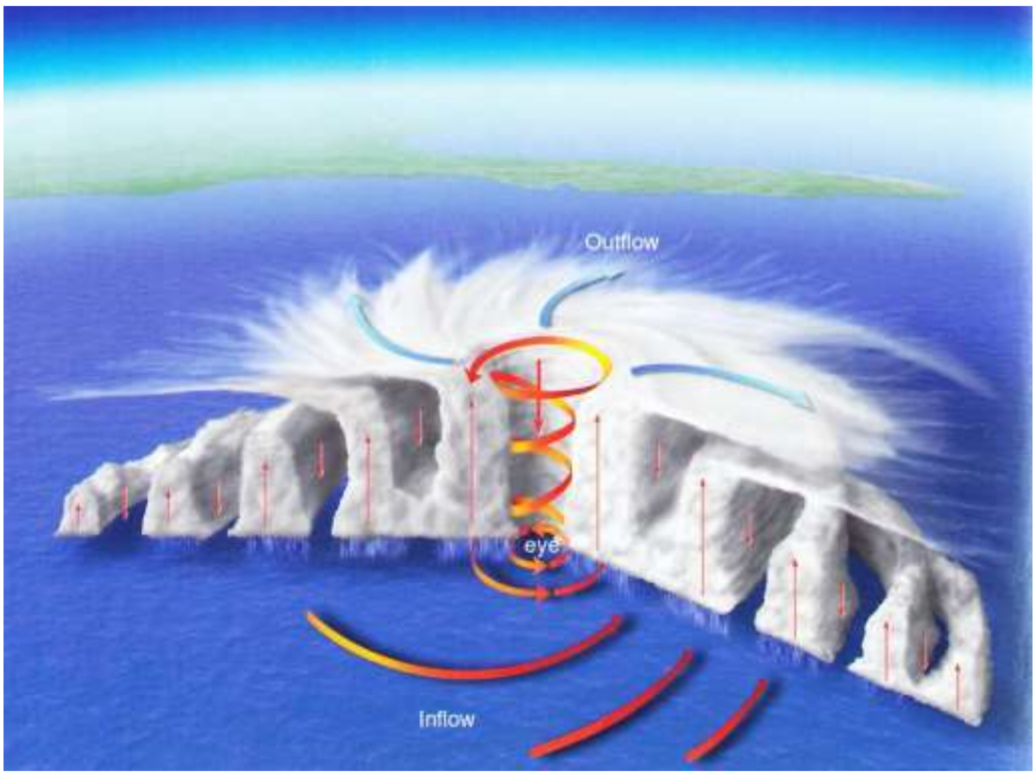
The photo is of a hurricane about 500km (310 miles) in diameter. The area of broken clouds in the center is the eye which is about 40 km (25 miles) wide. Within the eye, winds are light and clouds are broken. The surface air pressure is low – in this case 955mb (28.20 inches).

The clouds are aligned in circling bands called “spiral rain bands”. Surface winds increase as they blow counterclockwise in to the center.

Adjacent to the eye is the EYE WALL a ring of intense thunderstorms that circulate around the center and may reach up as high as 18 km (59,000 feet). In the eyewall are the fastest winds and the heaviest precipitation. In this one the winds were 105 knots (121 mph) with gusts up to 120 knots (138 mph)

As the hurricane passes, cirrostratus clouds appear, barometric pressure drops – slowly at first but faster later as the eye approaches, Winds blow from the N and NW with ever faster speeds. Huge waves (10 meters – 33 feet) and heavy rain showers follow. As the eye passes overhead winds slacken, rain stops, skies brighten, middle and high clouds appear overhead. The pressure is at its lowest. The eye passes and the situation reverses

A cut a way view of a hurricane:



Hurricanes form over tropical waters where there are light winds, humidity is high in a deep layer up through the troposphere. Surface temperatures are typically 26.5 C (80 F) or better. These conditions appear over the N Atlantic and N Pacific in the summer and fall. So hurricane season runs from June through November. Since the spin requires Coriolis, hurricanes cannot form on the equator but usually start 10 to 20 degrees north of it.

There needs to be a trigger for the hurricane to start. Winds CONVERGE along the ITCZ. Sometimes when a wave forms along the ITCZ an area of low pressure develops, convection becomes organized and the system grows into a hurricane.

Weak convergence also occurs on the eastern side of a tropical wave as well. Most hurricanes begin with tropical waves over Africa (only a small number of tropical waves become hurricanes). It appears that hurricanes are more numerous and stronger when the Western part of Africa is wet.

Even if all is well on the surface for hurricane development other things aloft may upset it. FOR EXAMPLE, trades winds near latitude 20N produce sinking air causing a “TRADE WIND INVERSION” If the inversion is strong it inhibits storm development. Strong upper level winds may produce shear and this also disrupts the formation. Strong winds aloft occur with El Niño hence there tend to be fewer hurricane in El Niño years. However warm El Niño years FAVORS hurricane formation in the northern tropical Pacific. La Niña years produce weaker Atlantic winds and this encourages development. The impacts of weather on places vert distant from where the event is actually happening are called **TELECONNECTIONS**.

Energy comes from direct transfer of sensible and latent heat from the warm ocean surface. A cluster of thunderstorms needs to form but how this happens is not clear.

However it happens the wind starts it counterclockwise spin as the thunderstorms move closer accelerating the movement. The warmer the water the greater the wind speed. Air moves into the center and this increases the speed which accelerates the evaporation and the overlying air becomes nearly saturated. This all fuels new thunderstorms. As the surface pressure lowers wind speeds increase and the system intensifies.

The maximum strength a hurricane can achieve is proportional to the difference between the temperature between the tropopause and the surface and to the potential for evaporation from the sea surface. The warmer the surface the lower the pressure and the higher the surface winds. There is a limit and peak gusts rarely exceed 200 knots (230 mph).

As long as the storm remains over warm water it may survive for a long time. Some have lasted as much as 24 days. Most last less than a week.

If the water beneath the eyewall cools by 2.5 degrees C the energy source is cut off and the storm dissipates. They also dissipate rapidly over land

STAGES OF DEVELOPMENT

Tropical depression (winds increase to 20-40 knots)

Tropical storm: (gets named) winds increase to 64 knots (74 MPH)

Hurricane when winds become greater than 74 mph (64 knots)

The actual path of the hurricane is apparently determined by the storm's structure and its interaction with the environment. There ARE MANY MODELS FOR PREDICTING THIS WHICH ARE OFTEN NOT IN AGREEMENT. Some make erratic turns, and take odd paths. Many head for the Gulf of Mexico, many head up the Atlantic Coast and make landfall on the Eastern seaboard or run up parallel to the coast and di out from the colder waters of the N Atlantic.

Eastern Pacific Hurricanes form off the Coast of Mexico (about 9 a year). They move westward away from the coast and little is heard about them. Moving northward gets them into cold water. Some turn back and hit the west coast and their remains may bring rains into s. California and Arizona. On one occasion rain produced flooding in Texas and Oklahoma. One actual hurricane hit the west coast near San Diego in 1858.

Major problems are often STORM SURGE

Hurricane warnings:

Hurricane watch is issued 24-48 hours before predicted arrival.

Hurricane warning is issued when it appears the hurricane will strike and area. This comes with a "probability" that indicates the chances the hurricane will come within 105 Km/65 miles of an area. The warnings are issued for rather large areas because of the size of the storms. The area is usually about 500km or 310 miles. The average swath of the hurricane is usually 1/3 that size there is considerable "overwarning"

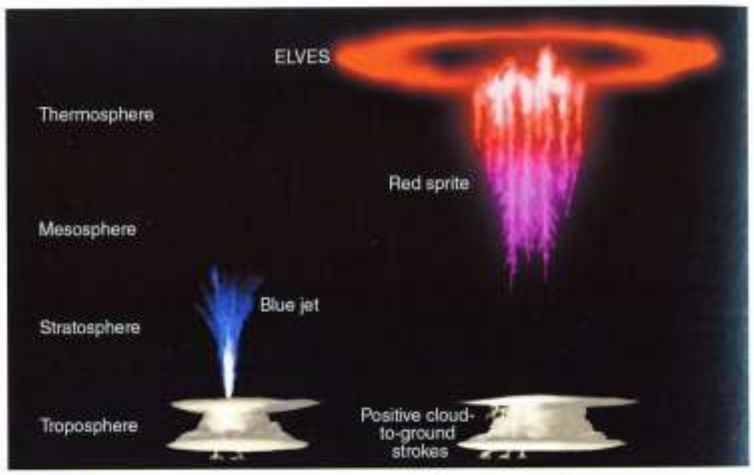
A SHORT BIT ABOUT ELECTRICAL DISCHARGES (ELVES) AT HIGH ALTITUDES

ELVES in the Atmosphere

For many years airline pilots reported seeing strange bolts of light shooting upward, high above the tops of intense thunderstorms. These faint, mysterious flashes did not receive much attention, however, until they were first photographed in 1989. Photographs from sensitive, low–light-level cameras on board jet aircraft revealed that the mysterious flashes were actually a colorful display called *red sprites* and *blue jets*, which seemed to dance above the clouds.

Sprites are massive, but dim, light flashes that appear directly above an intense thunderstorm system (see Fig. 3). Usually red, and lasting but a few thousandths of a second, sprites tend to form almost simultaneously with lightning in the cloud below and with severe thunderstorms that have positive cloud-to-ground lightning strokes. (Most cloud-to-ground lightning is negative.) Although it is not entirely clear how they form, the thinking now is that sprites form when positive lightning disrupts the atmosphere's electrical field in such a way that charged particles in the upper atmosphere are accelerated downward toward the thunderstorm and upward to higher levels in the atmosphere.

Blue jets usually dart upward in a conical shape from the tops of thunderstorms that are experiencing vigorous lightning activity (Fig. 3). Although faint, blue jets can be seen with the naked eye. They are not well understood, but appear to transfer large amounts of electrical energy into the upper atmosphere.



● FIGURE 3 Various electrical phenomena observed in the upper atmosphere.

*ELVES** as illustrated in Fig. 3 appear as a faint red halo — too faint to be seen with the naked eye, only with sensitive cameras. They occur in the ionized region of the upper atmosphere. ELVES occur at night and are extremely short-lived. They appear to form when a lightning bolt from an intense thunderstorm gives off a strong electromagnetic pulse (EMP) that causes electrons in the ionosphere to collide with molecules that become excited and give off light.

The roles that red sprites, blue jets, and ELVES play in the earth's global electrical system have yet to be determined.

*The acronym ELVES is from Emissions of Light and Very low frequency from lightning-induced electromagnetic pulsation sources.