Advanced Spotter Training 2009

Lesson 4: The Nature of Thunderstorms

From Last Time

- We discussed the different ways to make air rise.
- We discussed convection, convergence, and the different kinds of fronts.
- We studied how to find fronts on a surface chart.
- We studied how to find convergence on surface charts.
- We studied Skew-T diagrams and learned a little bit about CAPE.

This Lesson:

- The formation of thunderstorms.
- The life-cycle of a thunderstorm.
- The types of thunderstorms.

Homework Review

Go over the homework problems from last time:

- Make a diagram of each source of vertical motion.
- Explain how terrain can cause vertical motion.
- Analyze a current surface map for the position of fronts.
- Analyze a current surface map for regions of convergence.

Homework Review *(continued)*

- Analyze a local map for fronts and convergence at the surface.
- Write at least a paragraph on your understanding of how a thunderstorm producing outflow will influence its environment, even well removed from the thunderstorm.
- Analyze a current Skew-T diagram for severe weather potential. Explain your results.

Homework Review *(continued)*

- Explain why high-level speed shear is a favorable environment for the development of thunderstorms.
- Explain why CAPE might not be such a good indicator of severe weather potential, and describe when it is a good indicator.

Thunderstorm Formation

Once we have rising air, is this enough to tell you if thunderstorms will occur? No; it is a necessary, but not a sufficient, condition. Here is what really happens:

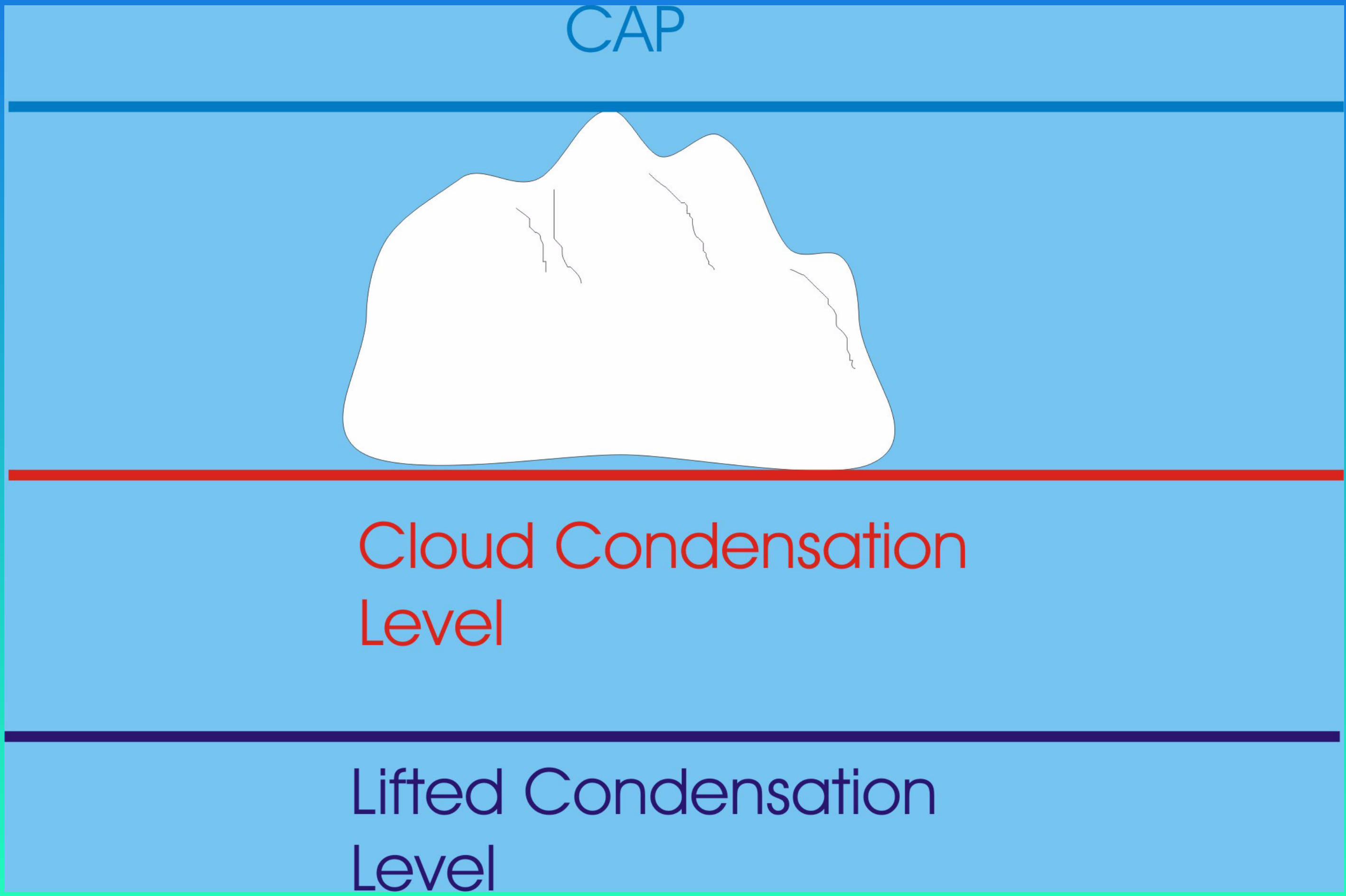
- As a glob of air (what we will call a *parcel*) rises, it cools.

Thunderstorm Formation *(continued)*

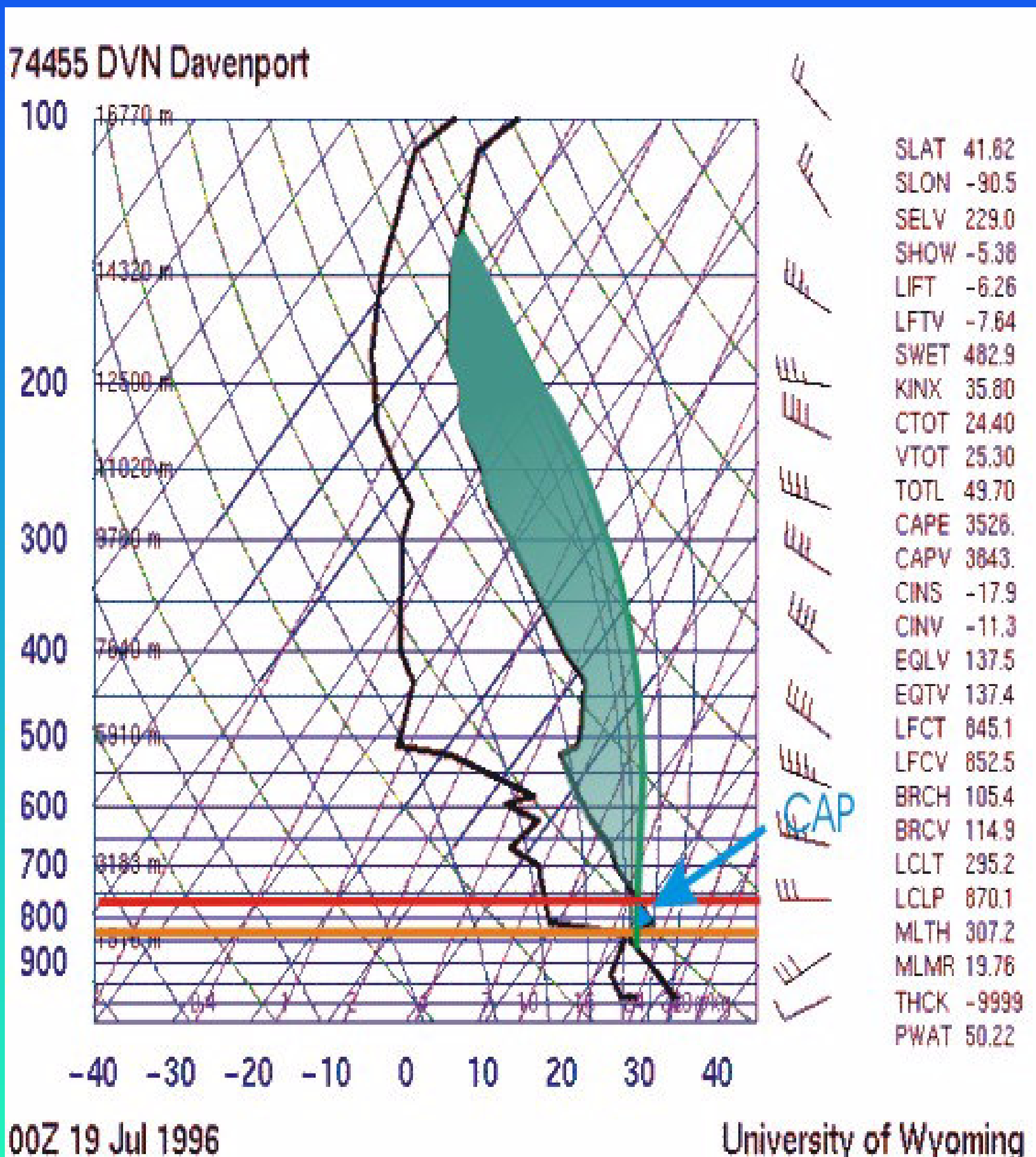
- At a certain altitude (depending upon local conditions) it will reach a temperature where the gaseous water in the air (called *water vapor*) is forced out of the air in the form of tiny droplets. This process is called *condensation*.
- The altitude where condensation occurs in an organized way is called the Lifted Condensation Level (LCL).

Thunderstorm Formation *(continued)*

- **Above this is the Cloud Condensation Level (CCL), this is where the cloudbase forms.**



Thunderstorm Formation *(continued)*

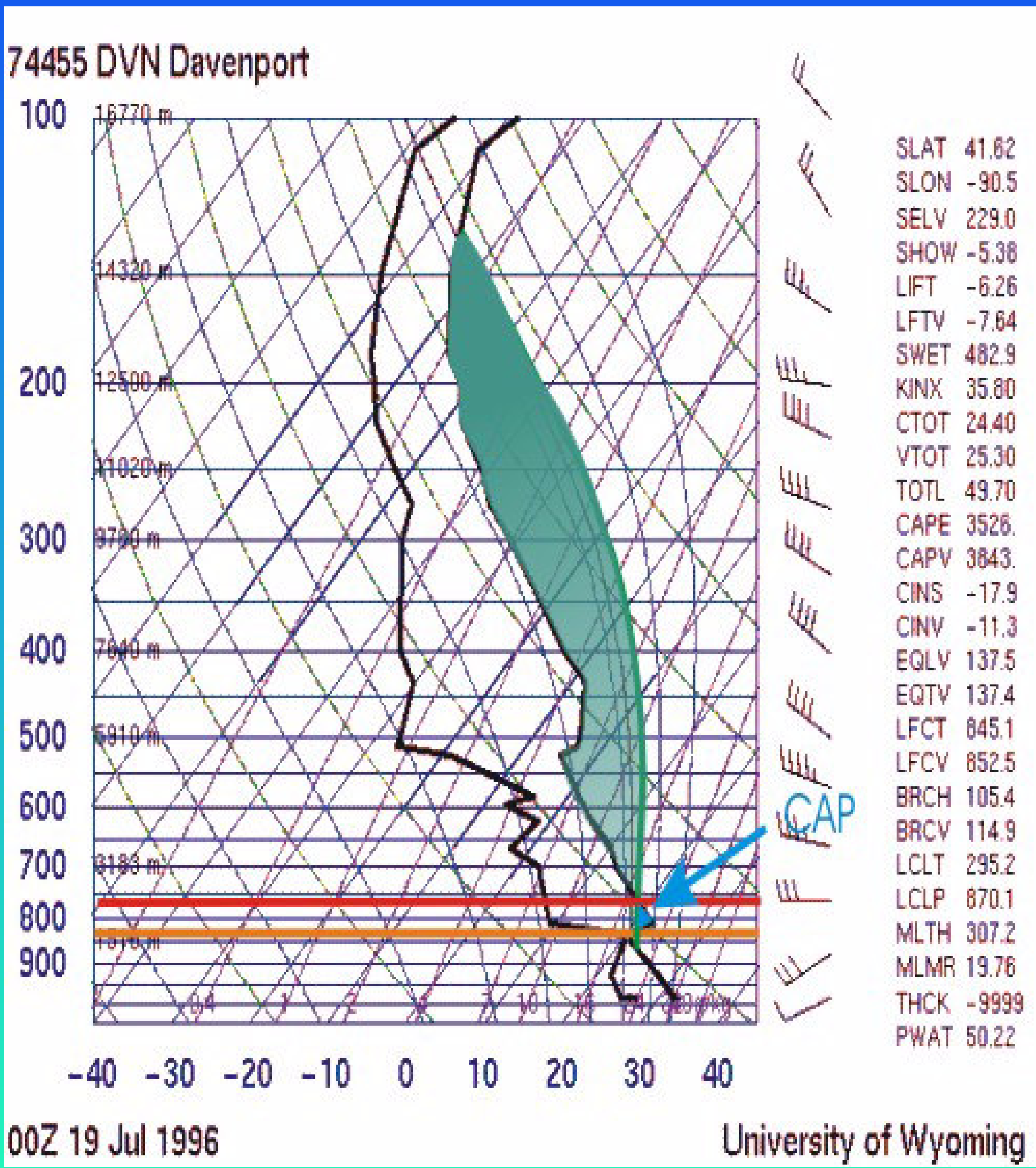


- If we look at a Skew-T we can find this level, (here the LCLP) at 870.1 millibars (in this case a little higher than 1500 meters).

Thunderstorm Formation *(continued)*

- Again, the LCL is where we will begin to see droplet formation, and the cloud bases will be at or a little bit higher than this level (CCL).
- Cloud tops will rise (in this case a few hundred meters) before reaching an area where they are cooler than their surroundings.

Thunderstorm Formation *(continued)*



- These same surroundings are also much drier, so clouds will evaporate into water vapor again.
- This is the area in blue called the CAP.

Thunderstorm Formation *(continued)*

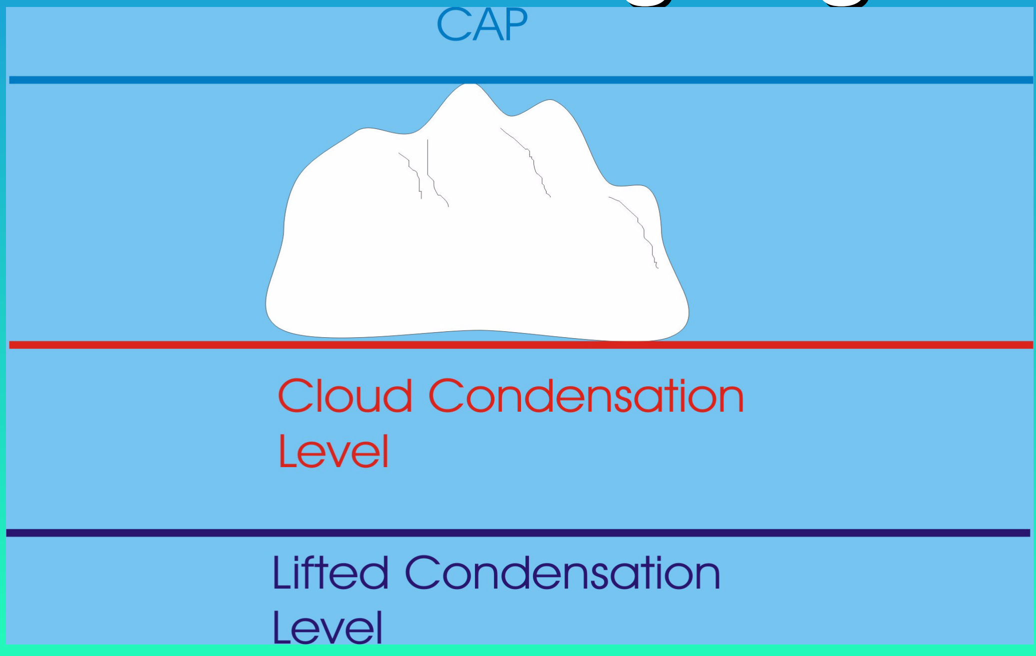
- The strength of the cap is called CIN (Convective INhibition), on the above Skew-T the CIN is -17.9 J/kg.
- Any CIN greater than -40 J/kg is weak enough that a strong forcing mechanism can break it. Note that this is negative, so greater is from -40 to 0 J/kg.
- If this cap is too thick, no parcels of air will be able to pass through and there will be no thunderstorms.

Thunderstorm Formation *(continued)*

- If this area is large (this area is the CIN mentioned above) then the cap will be too strong (too dry or too warm, or both) for the parcels to penetrate and there will be no thunderstorms.
- This is true even if the cap is thin.

Thunderstorm Formation *(continued)*

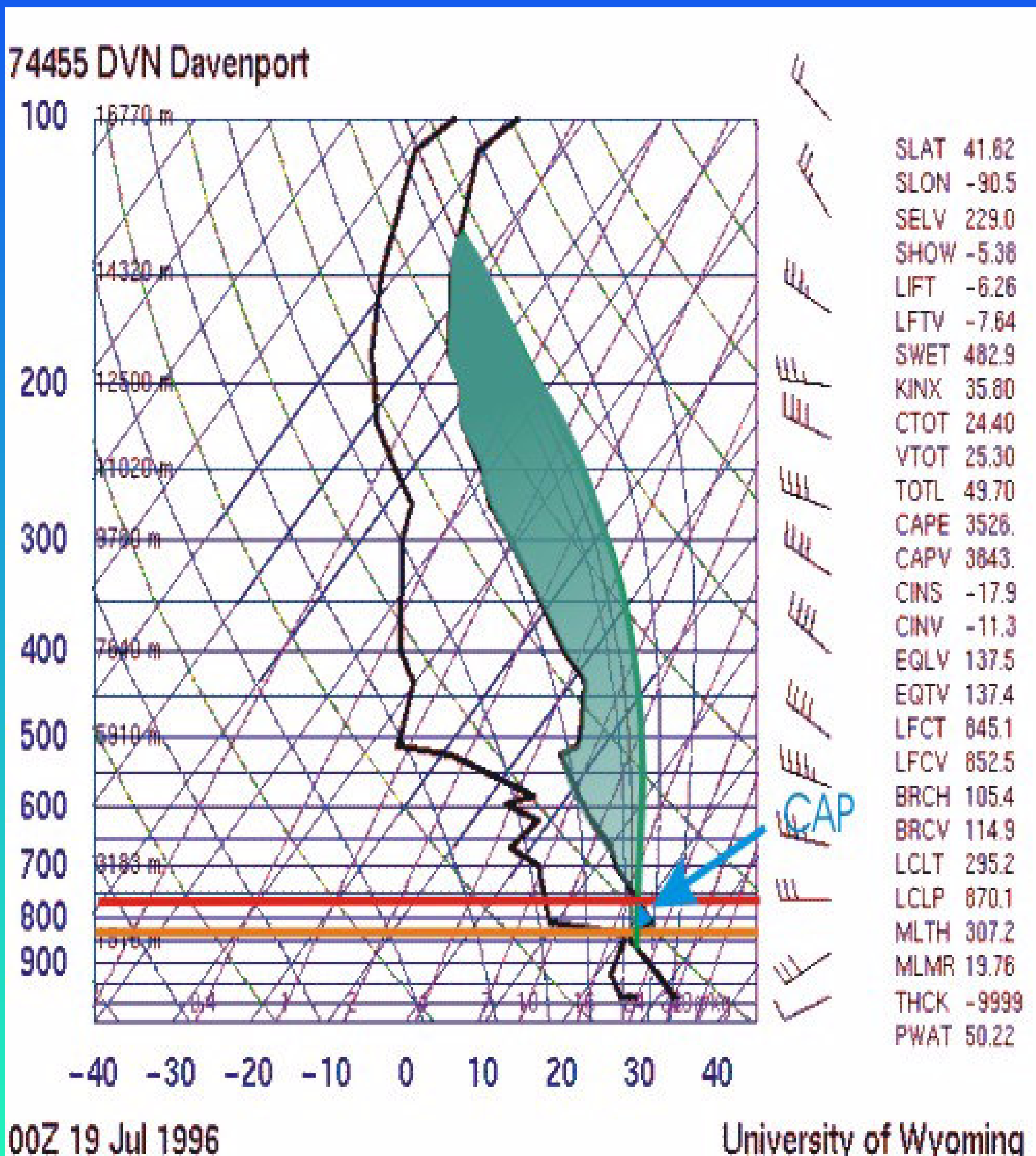
- At this stage in development we would see clouds with dark flat bases and a bubbly appearance above, like balls of cotton with flat bottoms.
- A visual clue that a cloud is undergoing convection is a cauliflower-like appearance to the cloud tops.



Thunderstorm Formation *(continued)*

- Only if the parcels of air are allowed to rise to a certain altitude where they are once again warmer than their surroundings (due to the heat released by condensation) will they be able to sustain their own vertical development.
- This occurs because the water vapor cools and condenses into cloud matter again, releasing a lot of heat.

Thunderstorm Formation *(continued)*



- This altitude is called the Level of Free Convection or LFC (on this Skew-T it is the LFCT).

Thunderstorm Formation *(continued)*

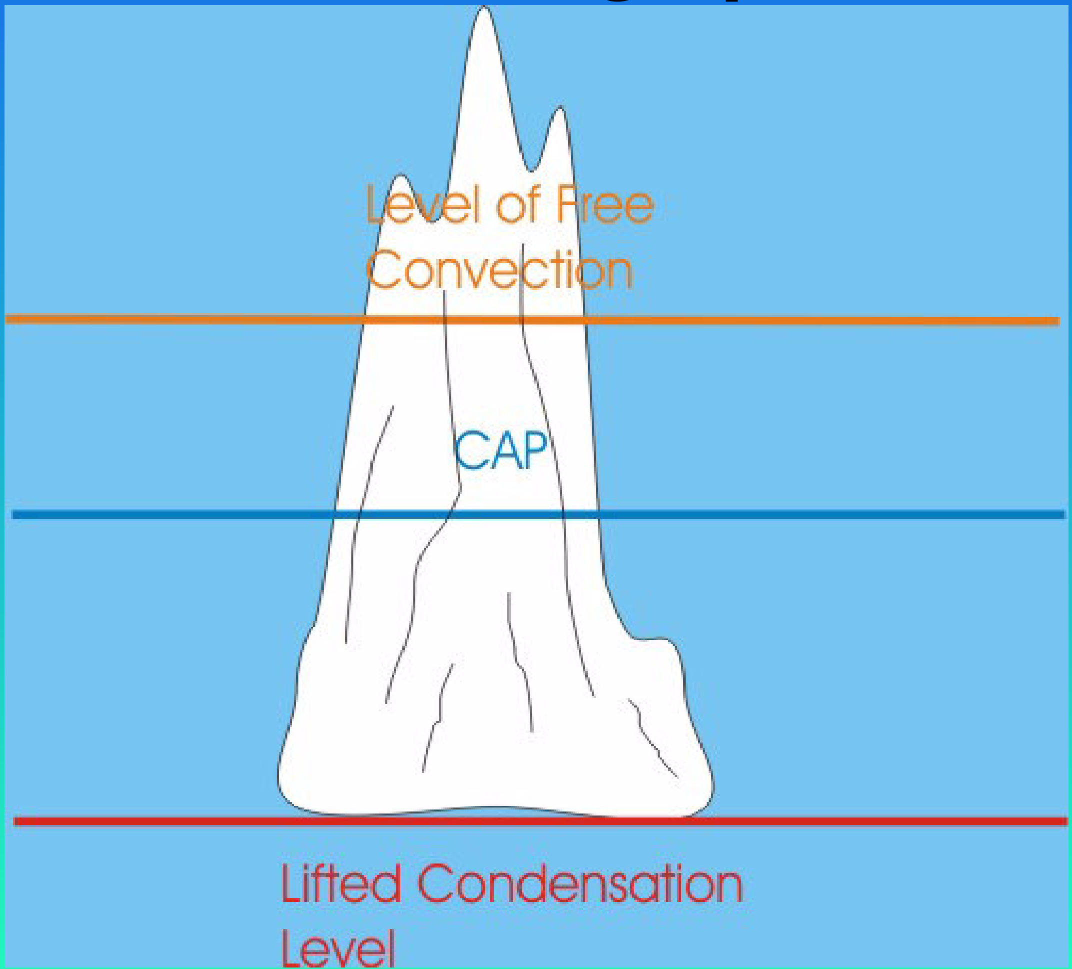
- Here you can see that this altitude is 845.1 millibars (around 2,000 meters high).

Thunderstorm Formation *(continued)*

- Once a parcel of air passes to this altitude it will be said to have "broken" the cap, and will then rise to a new altitude, called the equilibrium level, or EL (on this Skew-T it is EQLV, or 137.5 millibars, about 15,000 meters high; we would then estimate that thunderstorm tops could be as high as 50,000 feet).

Thunderstorm Formation *(continued)*

- As parcels of air begin to break the cap we might see plumes of cloud extending up from the tops of the bubbly clouds we saw before.



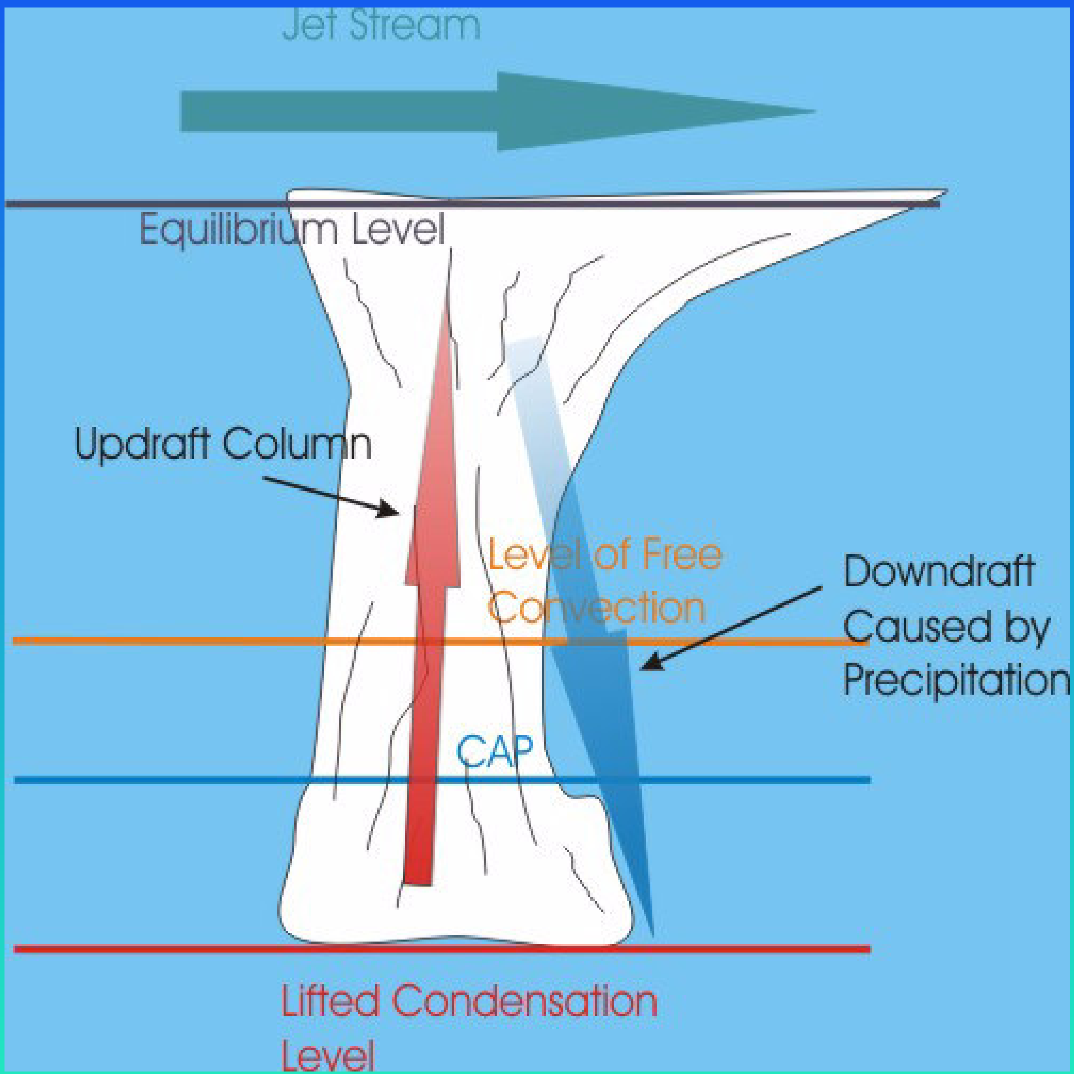
Thunderstorm Formation *(continued)*

- Such a structure might take on an almost tower-like appearance (which we call *towering cumulus*, or *towering-Q*).
- As the towers approach the equilibrium level the total number of water droplets increases and the droplets begin to coalesce into larger and larger droplets.

Thunderstorm Formation *(continued)*

- Eventually this will form rain drops that will be propelled out in front of the developing storm by the action of jet stream winds at the higher altitudes (this is one reason why it is important for vertical speed shear to exist).
- As the top of the tower intersects with the upper level winds, it gets blown off downstream, thus forming the classic anvil.

Thunderstorm Formation *(continued)*



- **As the raindrops accumulate out ahead of the rising column of air (the updraft column), the drops begin to fall to the ground.**

Thunderstorm Formation *(continued)*

- In most cases, the temperatures in the anvil are so cold (despite the heat of the updraft) that precipitation initially forms as snow instead of raindrops.
- As the precipitation falls, it turns to rain and air gets pulled down with it by friction; thus you get a downdraft out in front of the developing storm.
- At this stage you may begin to have ice crystals forming in the anvil.

Thunderstorm Formation *(continued)*

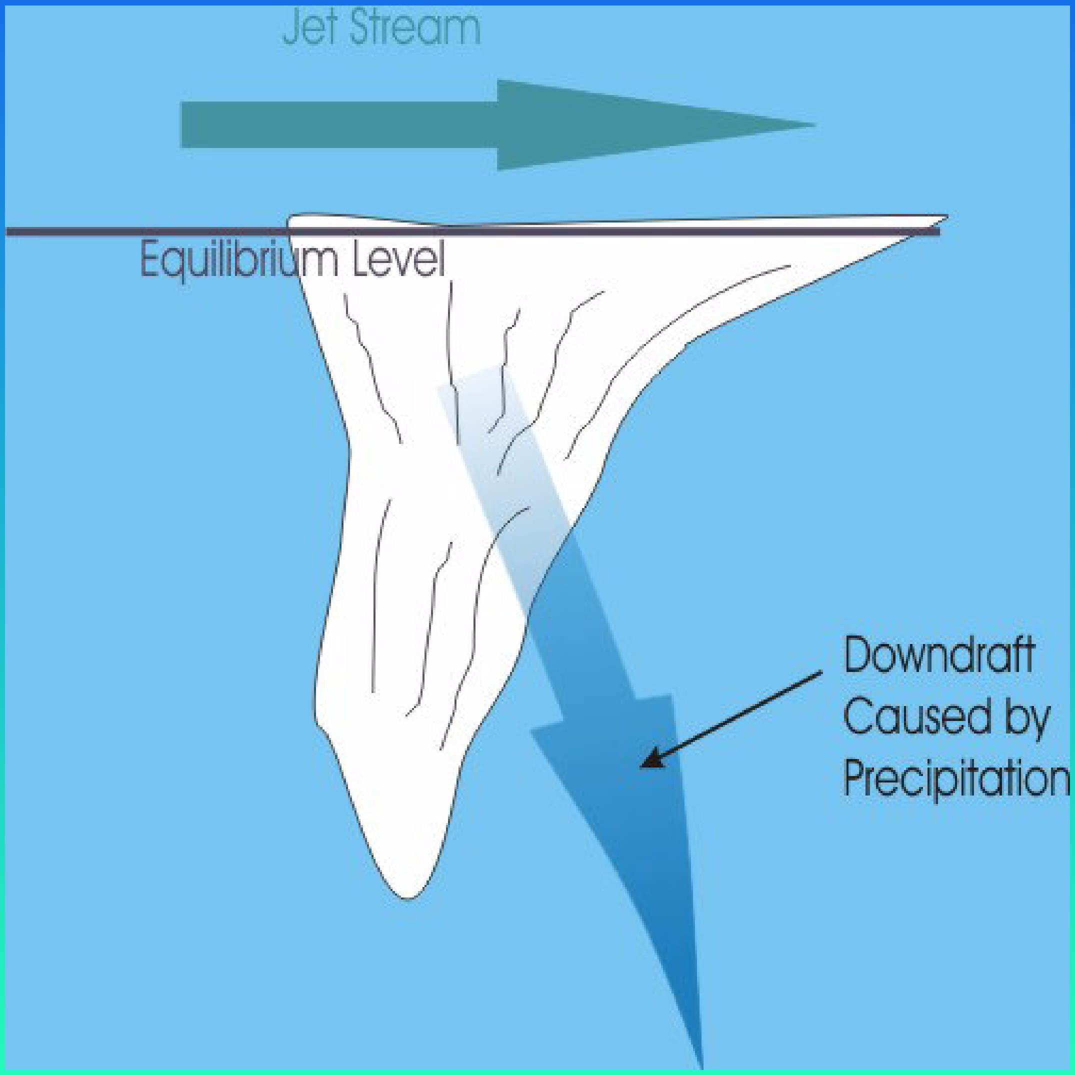
- The collisions between these ice crystals can ionize the ice crystals (by stripping off electrons) and build up substantial accumulations of charge.
- If the differences between these areas of accumulated charge become large enough, lightning will result.

Thunderstorm Formation *(continued)*

- Eventually, a thunderstorm will lose its updraft and the downdraft will continue for a time (and will likely produce precipitation and wind).
- This is the stage where isolated storms can transform into squall lines, as we will see in later in this lesson.

Thunderstorm Formation *(continued)*

- After a time, the only remaining part of the thunderstorm, will be the (now detached) anvil cloud; what we call *thunderstorm debris*.



First Discussion!

- Discuss the development of thunderstorms.

Section 2

The Isolated Thunderstorm and the Supercell

More About Thunderstorms

There are basically two kinds of isolated storms.

- The first is your garden-variety *isolated thunderstorm*, sometimes called an *air-mass thunderstorm* because it can form away from any fronts.
- The second is of great concern to us and is called the *supercell thunderstorm*.

The Isolated Thunderstorm

- Sometimes referred to as *air-mass thunderstorms*, these storms develop when a convective column gets strong enough to reach the LFC, or you get a boundary interacting with local prevailing winds, or some combination of these.

The Isolated Thunderstorm *(continued)*

- Such storms will generally have a very disorganized vertical wind profile; thus they will tend to be short-lived.
- This type of vertical wind profile indicates that storms will tend to develop straight up, or nearly so.
- When precipitation begins to develop, it will fall into the updraft.

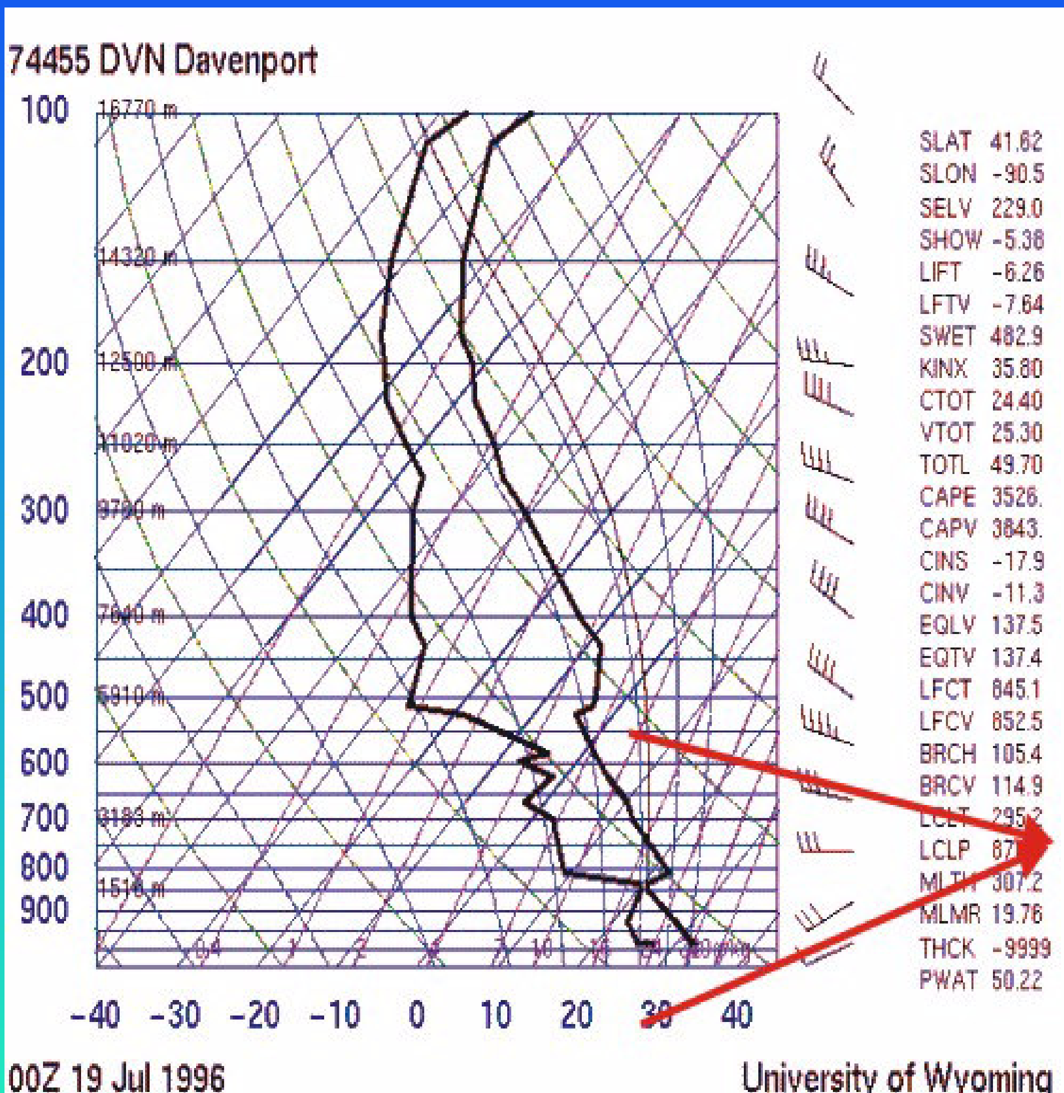
The Isolated Thunderstorm *(continued)*

- After a certain point, the updraft will be overcome by the precipitation and the storm will dissipate.
- This takes, on average, 20 minutes.

The Supercell Thunderstorm

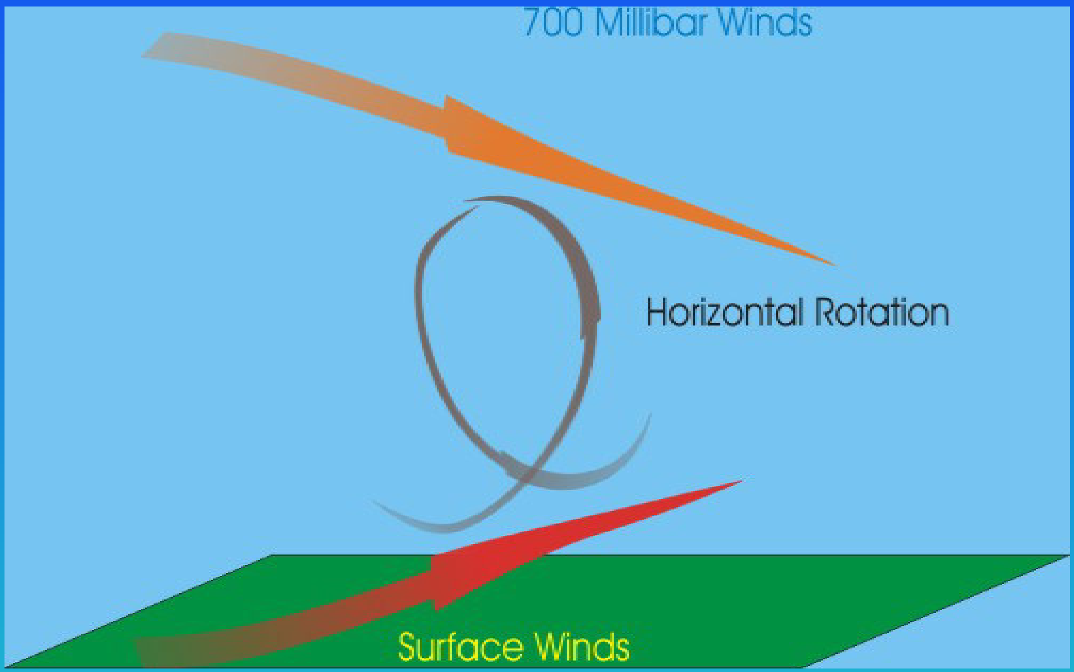
- This is a thunderstorm that develops a persistent and strong rotation about a vertical axis.
- Such rotation usually occurs in an area of a couple of miles in diameter and is called a *mesocyclone*.
- These storms are responsible for a good percentage of the severe weather that occurs.

The Supercell Thunderstorm *(continued)*



- Here we have surface winds coming out of the southwest and winds about 700 millibars coming more from the west. This gives us about a 30 degree angle of shear.

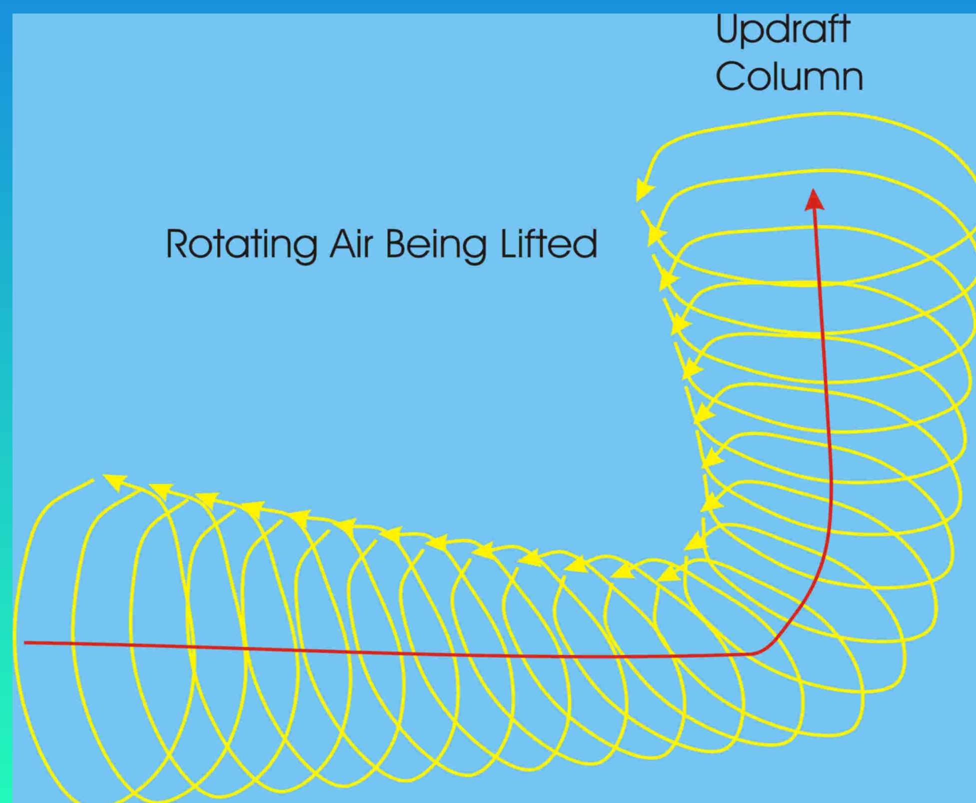
The Supercell Thunderstorm *(continued)*



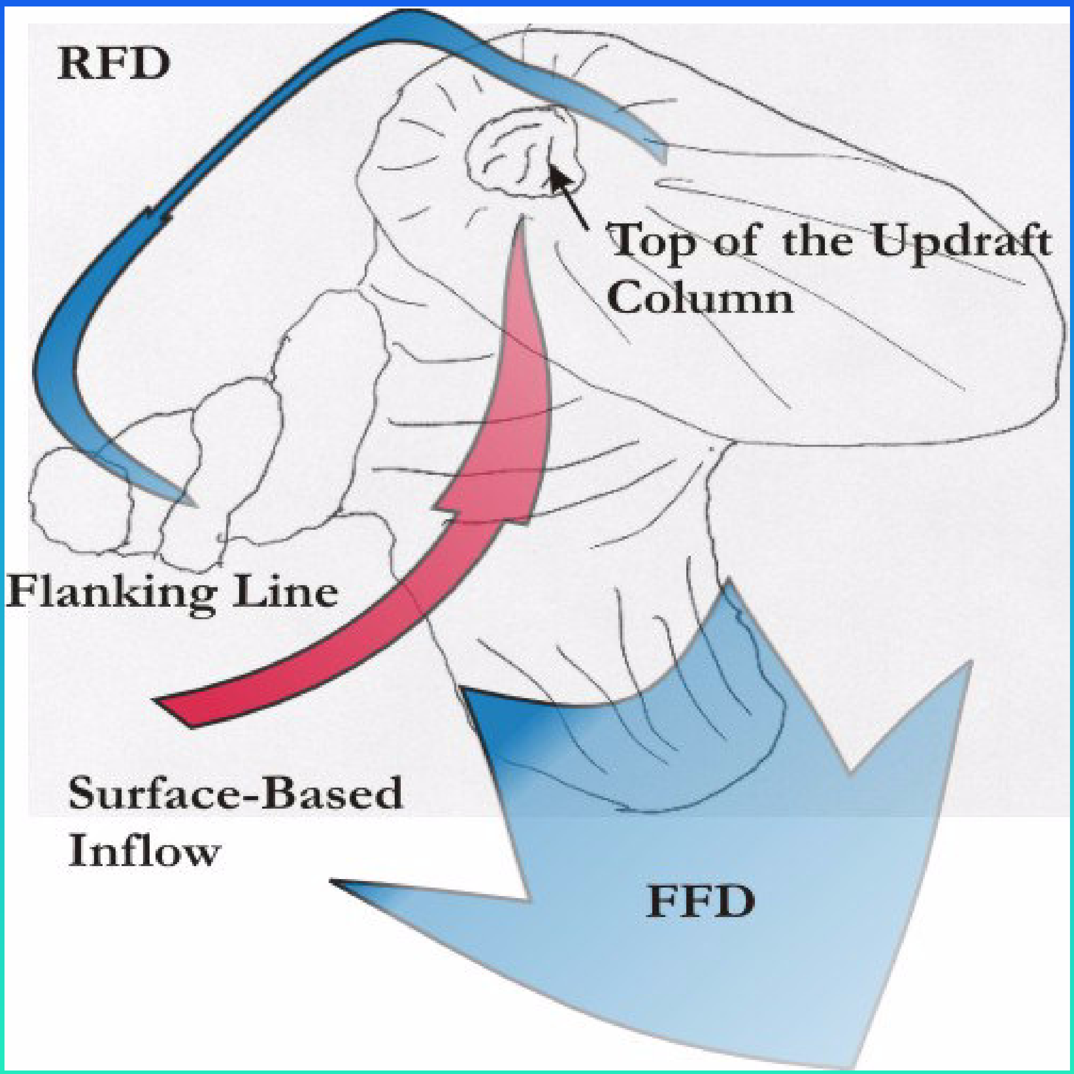
- This indicates that there is a rotation about a horizontal axis between these altitudes.

The Supercell Thunderstorm *(continued)*

- When an updraft or other vertical forcing mechanism occurs, this rotation can become tilted upward.
- This will result in a rotation about a vertical axis.
- It is believed that this is one way that a mesocyclone is formed.



The Supercell Thunderstorm *(continued)*



- The classic supercell (which is rarely seen in nature) is depicted to the left.
- The updraft column is where the mesocyclone can be found.

The Supercell Thunderstorm *(continued)*

- Note that this diagram has a visual clue that there is a very strong updraft present; there is cloud matter piling up above the anvil.
- This is called an *overshooting top*, it indicates that the updraft is strong enough to punch through the jet stream itself.

The Supercell Thunderstorm *(continued)*

- The flanking line contains developing updraft columns that will be drawn into the supercell and replace the currently dominant updraft.
- Inflow frequently occurs at the surface and at both the 850 millibar and 500 millibar levels.
- Otherwise, it is similar to other thunderstorms you might see.

The Supercell Thunderstorm *(continued)*

- You might see broad and flat-looking ribbons of cloud matter flowing into the storm near the surface or aloft (at the 500 millibar level, for example).
- These are regions of warm-moist inflow, and are sometimes called *beaver-tails* because of their broad-flat appearance.
- When such bands are flowing into the storm, it is a visual clue that there is lots of fuel for the storm updraft.

The Supercell Thunderstorm *(continued)*

- These are all clues that the storm will be long-lived.
- The important thing to remember about supercells is that they are developing new cells in the flanking line that are being drawn into the thunderstom as it progresses.
- The supercell will dissipate ***only*** when it loses the capability to generate new cells.

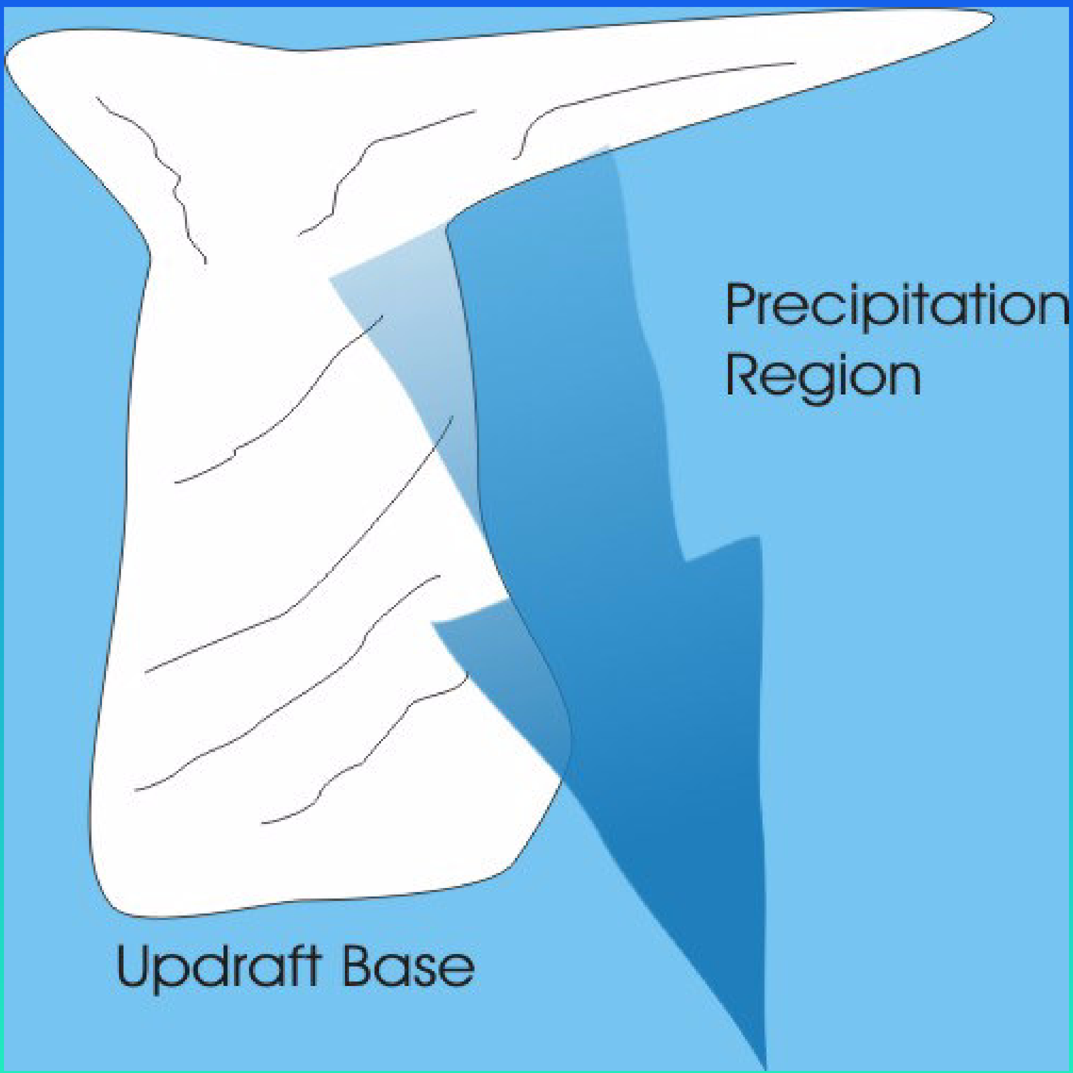
Supercell Variations

- The classic supercell is almost never seen.
- Real supercells will be combinations of some of the characteristics of the classic mixed with either of the next two variants.
- Some supercell thunderstorms develop in dry environments.
- These are called *Low Precipitation Supercells* or LP storms.

Supercell Variations *(continued)*

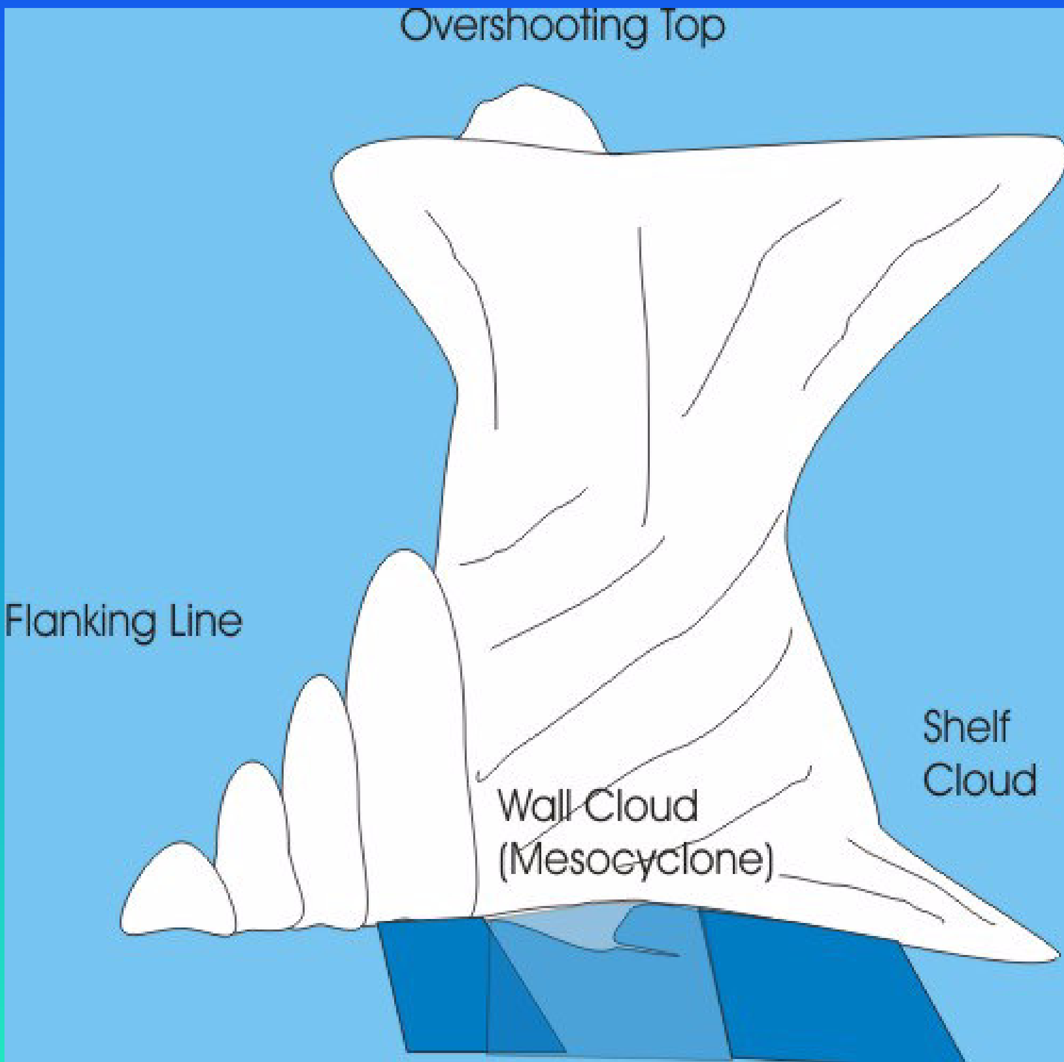
- They can form when mid-level moisture is the driving source of condensation.
- Often the precipitation goes into the formation of the anvil, rather than reaching the ground.
- Such thunderstorms are characterized by their high bases.
- Storms like this are sometimes called *elevated storms*.

Supercell Variations *(continued)*



- These storms can form above existing low-level cold domes of air, in essence treating the top of the cold dome as the ground.
- The other extreme occurs, too.

Supercell Variations *(continued)*



- **Supercell storms that have an abundance of moisture are called *High-Precipitation Supercells* or HP storms.**

Supercell Variations *(continued)*

- These are often the most violent storms that you can encounter on Earth.
- Note that rain is wrapping entirely around the mesocyclone.
- If there were a tornado in the rain-wrapped area (what chasers call, *"The Bear's Cage"*), it would be difficult if not impossible to see; that is one reason why these storms are so dangerous.

Second Discussion!

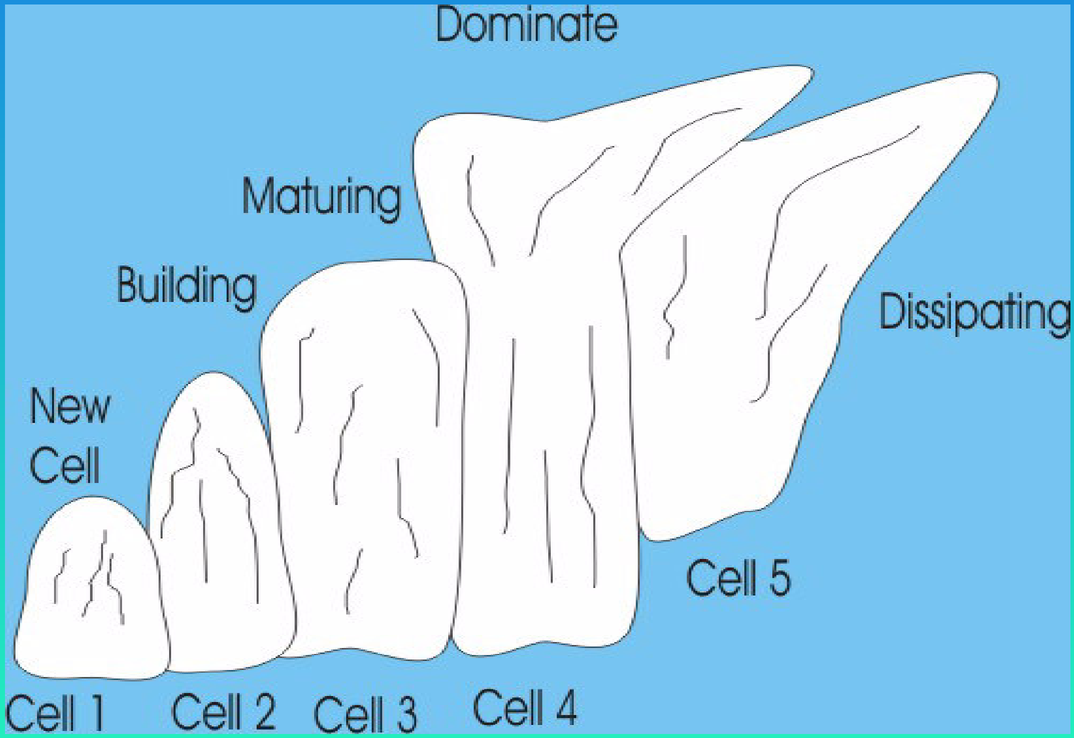
- Think about the level of danger posed by individual storms.

Section 3

Thunderstorm Systems

Multicell Clusters

- Frequently you will see a structure like this.



Multicell Clusters *(continued)*

- Here is a photograph donated by Virginia Randell of Kenosha, Wisconsin. Note the cells in different stages of development.

Multicell Clusters *(continued)*

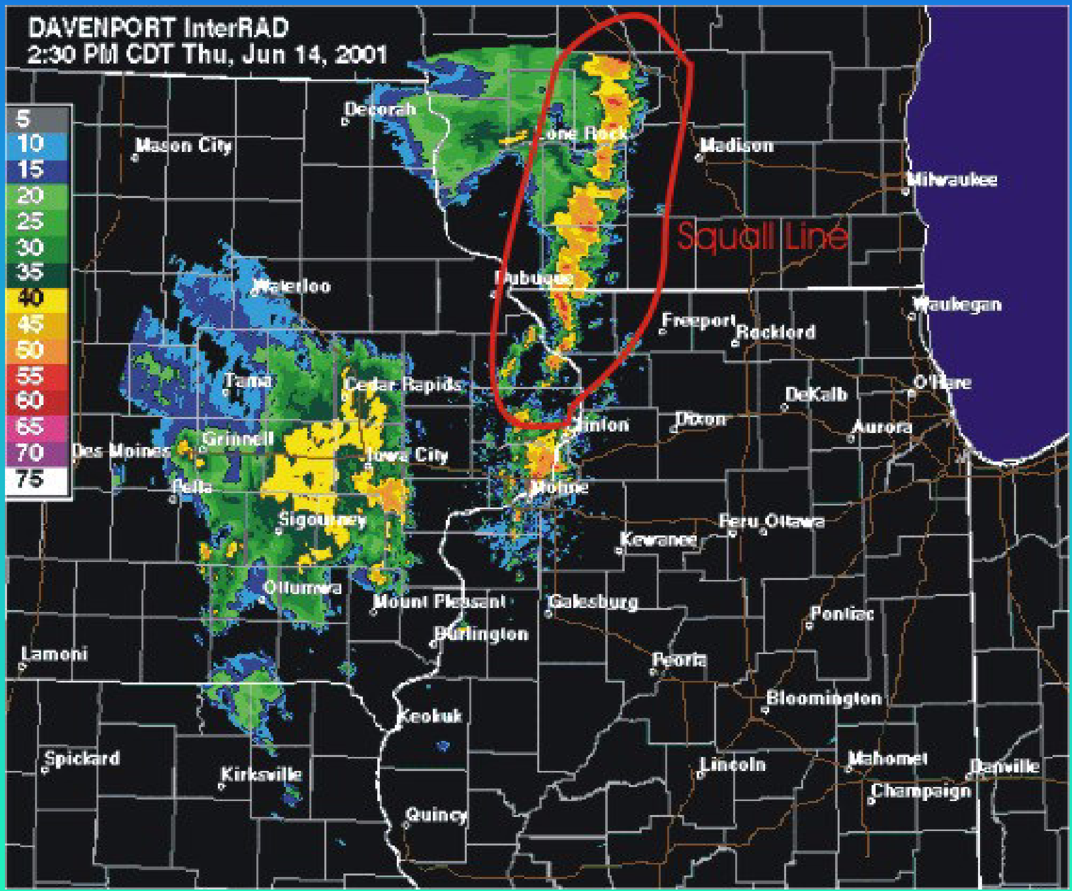
- Here the storms are developing from the forcing point (where new cells are developing) downwind (to the right in both the drawing and the photograph).
- Successive cells will start, mature, become dominant, and then dissipate.
- This occurs in a line pattern extending downstream from the source of thunderstorm development.

Multicell Clusters *(continued)*

- This is sometimes called a *storm train*.
- No cell will be likely to exist for more than a half hour.
- The severe threat from any cell is minimal, though the entire cluster can produce a lot of severe weather.
- Most often severe weather occurs in the dissipating cell, as this is downdraft-dominant.

Squall Lines

- Frequently you will see lines of thunderstorms on radar, similar to this.

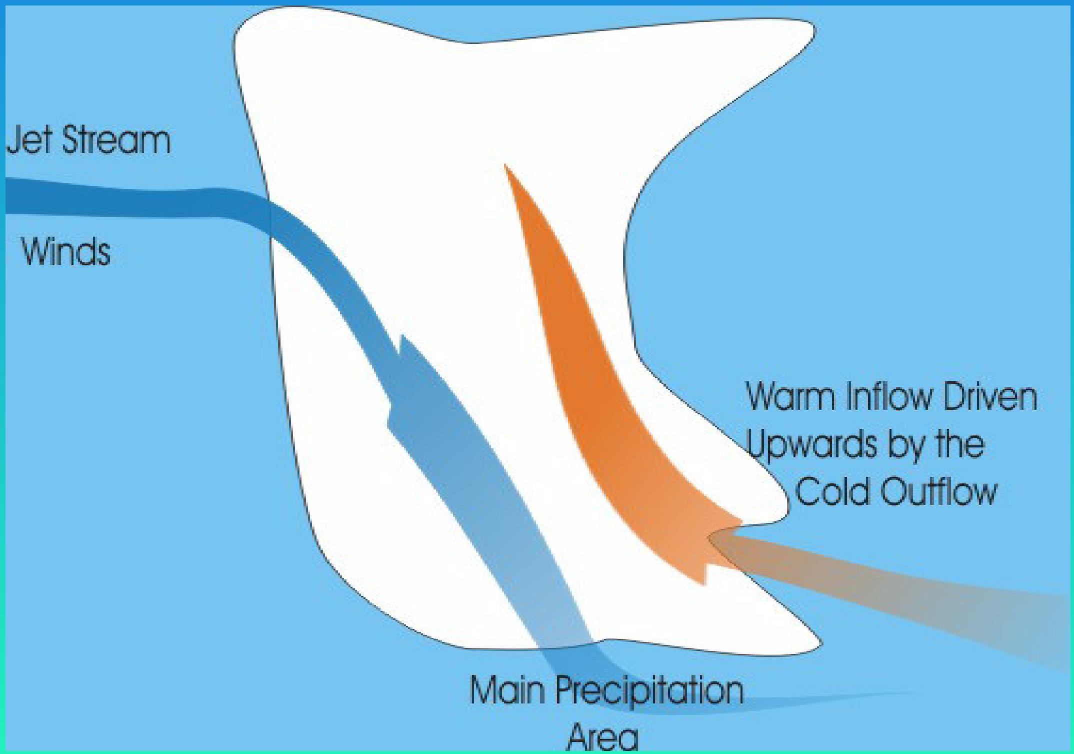


Squall Lines *(continued)*

- Here thunderstorm cells form on the right-hand (in this case lower) side of the line and propagate to the left (in this case upwards) through the line and eventually dissipate as the line itself moves forward (in this case from left to right).
- In some ways, the squall line is reversed from the structure of a classic storm since its inflow is from the front.

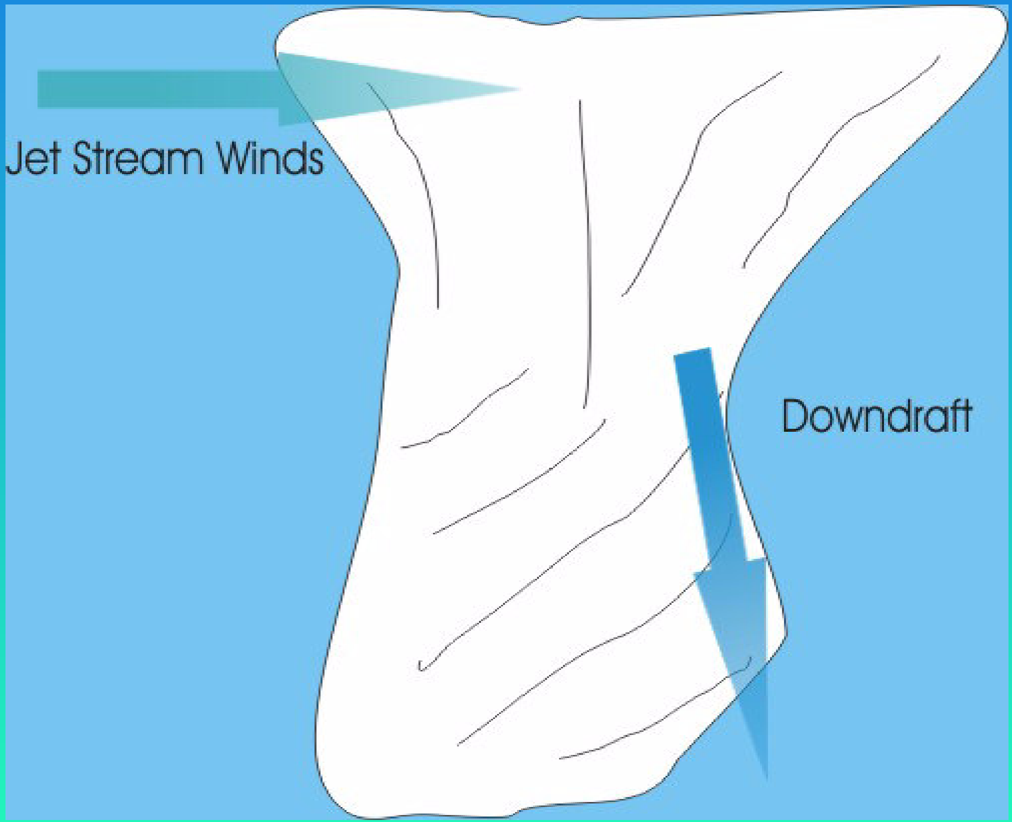
Squall Lines *(continued)*

- Here we see that mid- or upper-level winds can be brought down to ground level by the downdraft.



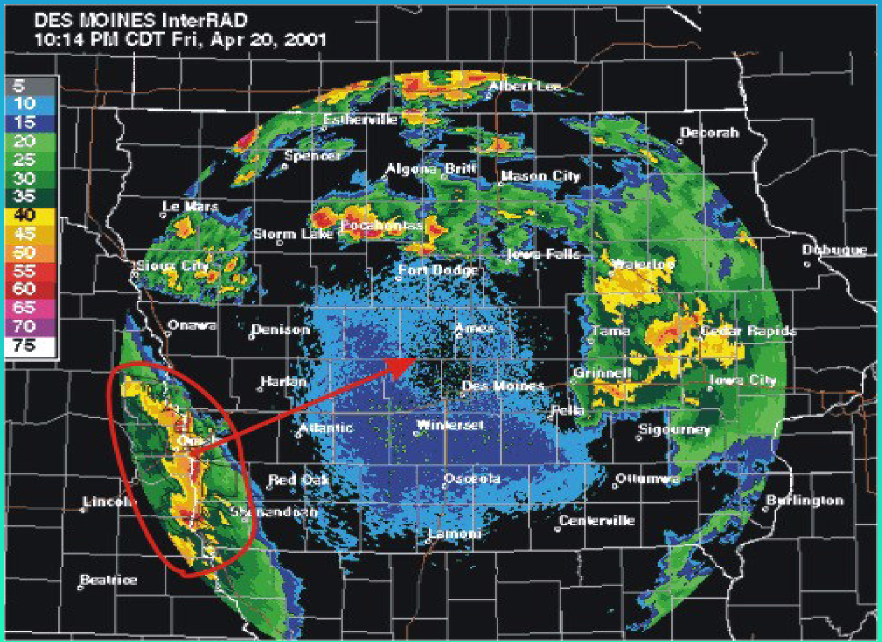
Squall Lines *(continued)*

- Here is one common way for squall lines to develop, we begin with a supercell that goes into the dissipating stage.



Squall Lines *(continued)*

- Mid-level winds are brought to the surface by the increased downdraft, this causes strong outflow in the front of the storm.
- This causes an updraft in the front of the storm, a snow-plow effect.
- On radar there will be a characteristic bow echo.



Squall Lines *(continued)*

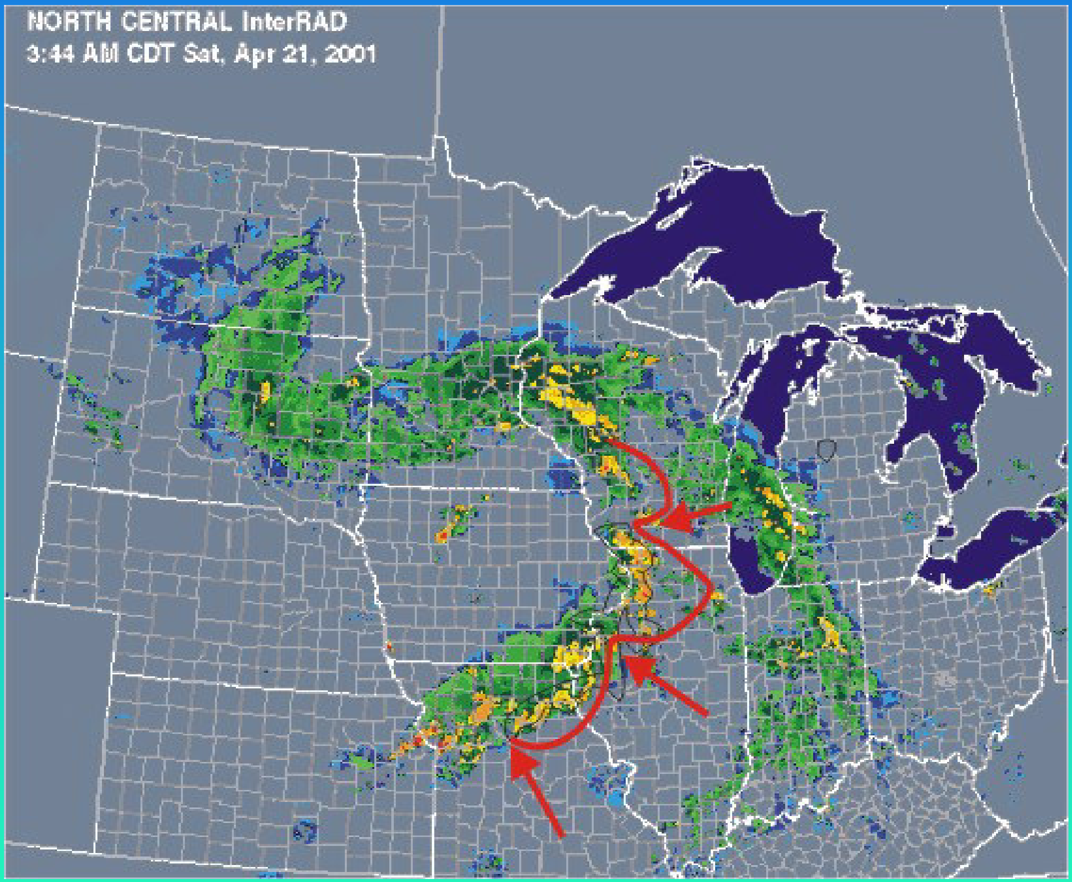
- This forward-flank updraft, coupled with a rear-flank downdraft causes precipitation to fall on the rear-flank.
- This process continues until the upper level support ceases.

Squall Lines *(continued)*

- While it is very rare (I know of only two cases in my nearly thirty years of spotting and chasing) tornadoes can form in this forward updraft.
- It is possible for regions of a squall line to develop supercell characteristics.
- This usually is due to inflow jets that form on the leading edge of a squall line.

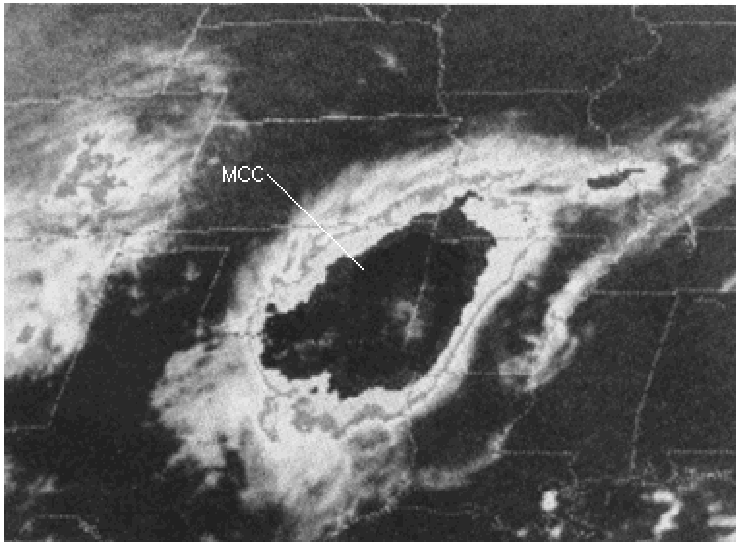
Squall Lines *(continued)*

- Such a structure is called a *Line Echo Wave Pattern* or a LEWP.
- Storms that form in the cusps may develop inflow regions to the right, similarly to a supercell.
- They can develop mesocyclones.



Mesoscale Convective Complexes

- A mesoscale convective complex (MCC) is characterized by a large circular cold cloud shield (anvil), as seen on a satellite photograph. This photo is from the web site: http://meted.ucar.edu/mesoprim/severe2/print_version/_p_5.0MCCs.htm .



IR satellite image for 1200 UTC 07 July 1982

Modified from Menard and Fritsch 1989

Mesoscale Convective Complexes *(continued)*

- Occasionally, and usually at night, a large circular region of convection can begin to develop thunderstorms.
- This region of convection is initiated by the approach of a trough of low pressure when it couples to a low-level jet that will feed sufficient moisture into the system.

Mesoscale Convective Complexes *(continued)*

- This will last hours as new cells form on the outflow of dissipating storms coupling with the source of convection.
- Such systems are responsible for most of the summer nighttime precipitation.

Final Discussion!

- Think about the level of danger posed by systems of storms.

Homework Due Next Week

- Develop a series of diagrams to explain the life-cycle of an average thunderstorm.
- Analyze a current Skew-T and locate the cap, if it exists.
- Speculate on why the dissipating stage is often accompanied by strong winds.
- Explain why isolated storms have only a low-probability for developing severe weather.
- Explain why supercells are so dangerous.

Homework Due Next Week *(continued)*

- Speculate on the shape of a supercell that splits into a right (cyclonic) and left (anticyclonic) part.
- Develop a diagram of a supercell and point out the visible features that make it different from an isolated storm.
- Make a diagram of a thunderstorm cluster and speculate on its capability to produce severe weather. Where will such severe activity be likely to occur?

Homework Due Next Week *(continued)*

- Why are squall lines so dangerous?
- Explain the structure of a squall line.
- Speculate on the severe weather potential of an MCC.