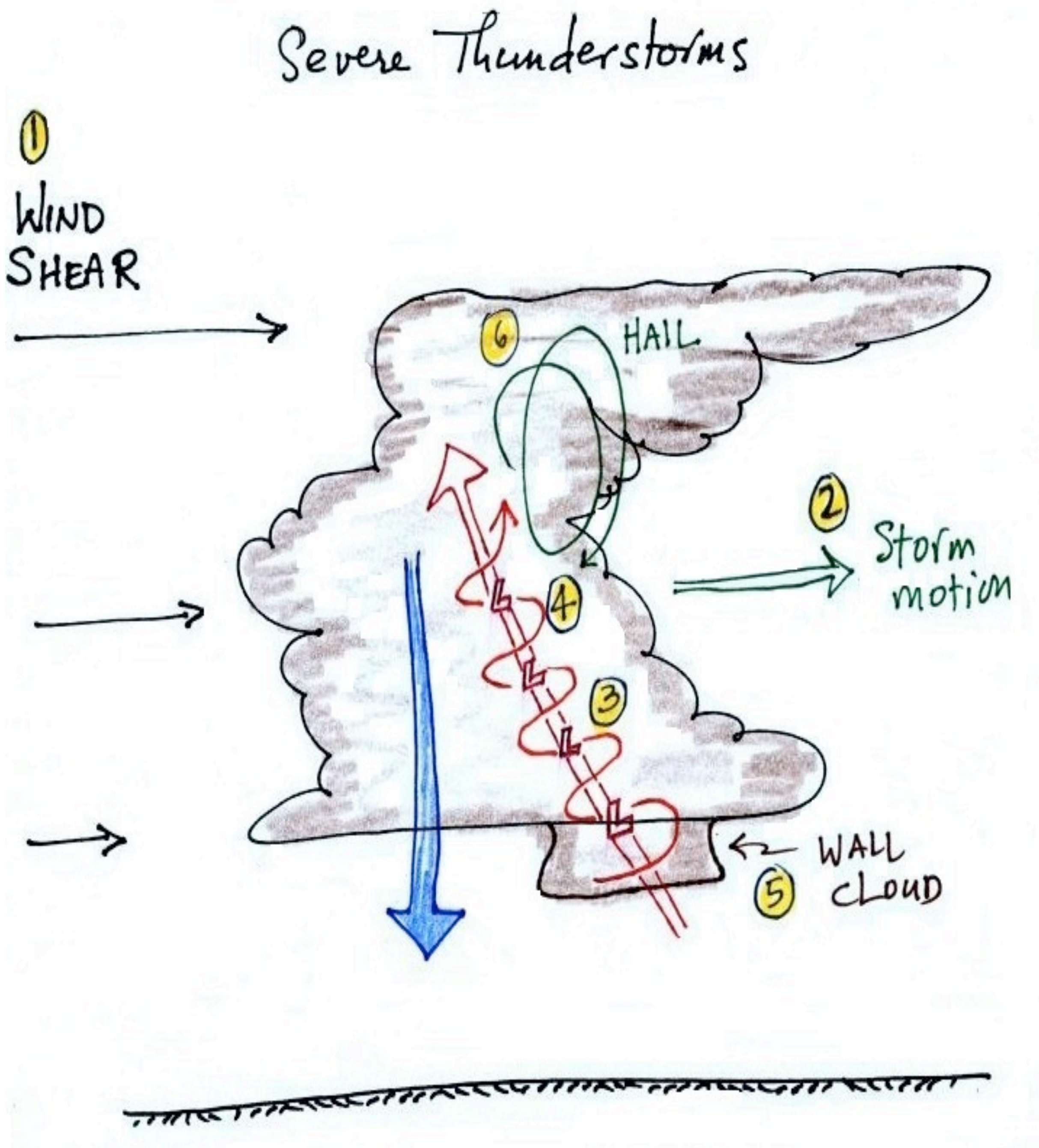
Module 11 - Lecture 31

In this lecture we will briefly look at the internal structures of severe and supercell thunderstorms. We will also look at tornadoes.

Severe or Supercell Thunderstorms

This figure is a schematic diagram of a severe thunderstorm. The points on the following page correspond to the diagram.



1. **Veritical wind shear** means that the wind speed is changing speed and/or direction with altitude. Severe storms are more likely to form when there is vertical wind shear, especially if the wind speed is increasing with altitude.

2. The thunderstorm is moving to the right with the wind. It is moving more rapidly at the top of the thunderstorm than at the bottom where the updraft begins. Rising air that is situated at the front bottom edge of the thunderstorm will find itself near the back edge of the storm when it reaches the top of the cloud.

3. The differential wind speed produces a tilted updraft. The downdraft is located at the back of the cloud. In a moving thunderstorm, the updraft is continually moving to the right and staying away from the downdraft so that it does not extinguish the updraft, unlike a simple or air mass thunderstorm. Consequently a severe thunderstorm can last longer and intensify more than a simple or air mass thunderstorm.

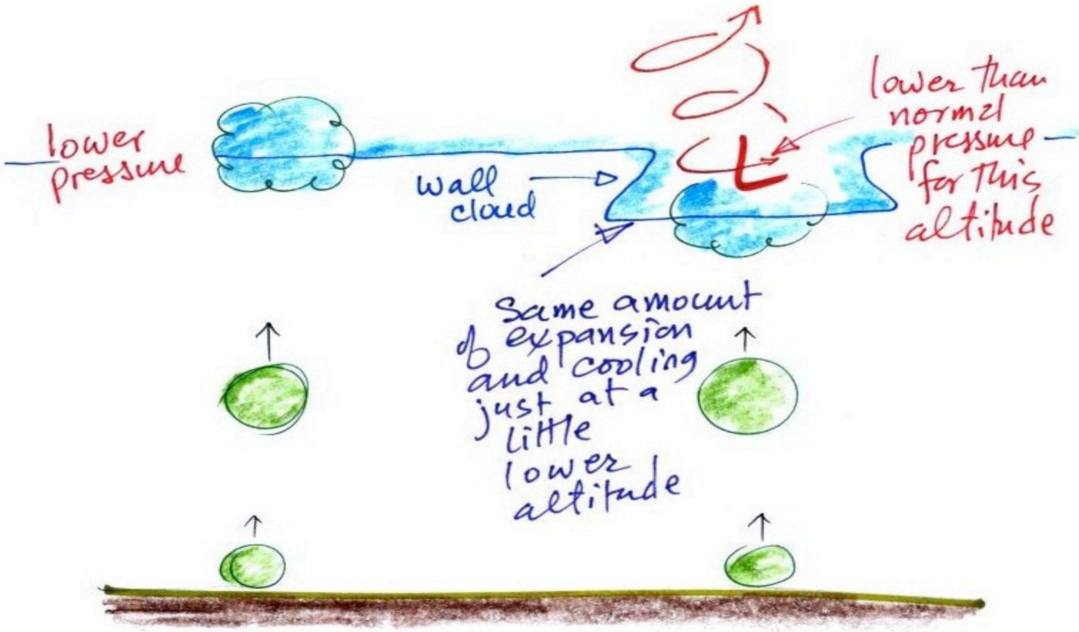
4. Wind shear can also cause the tilted updraft to rotate. A rotating updraft is called a **mesocyclone**. Meso refers to medium size (thunderstorm size) and cyclone means winds spinning around low pressure. The low pressure in the core of the mesocyclone creates an inward pointing pressure gradient force that keeps the updraft winds spinning in circular path. A low pressure core also keeps the winds spinning in a tornado.

5. The cloud that extends below the cloud base and surrounds the mesocyclone is called a **wall cloud**. The largest and strongest tornadoes will generally come from the wall cloud.

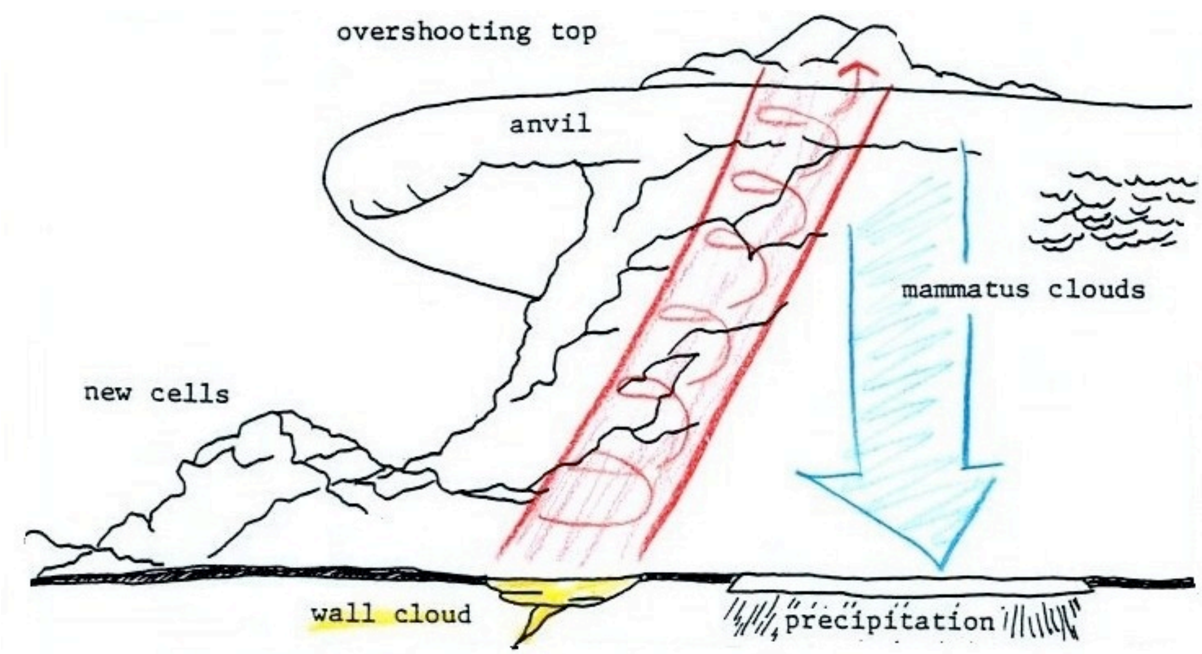
6. A tilted updraft keeps growing hailstones inside the cloud instead of falling to the ground. The updraft carries hailstones toward the top of the cloud. When the hailstones begin to fall, the strong updraft carries them upward again and the hail increases in size. The formation of large hailstones (three fourths of an inch or larger) is one of the criteria meterologists use to identify a severe thunderstorm.

A wall cloud can form slightly below the rest of the base of the thunderstorm; the figure on the next page explains why that is true. Clouds normally form when air rises, expands, and cools as shown above at left. The rising air expands because it is moving into lower pressure surroundings at a higher altitude.

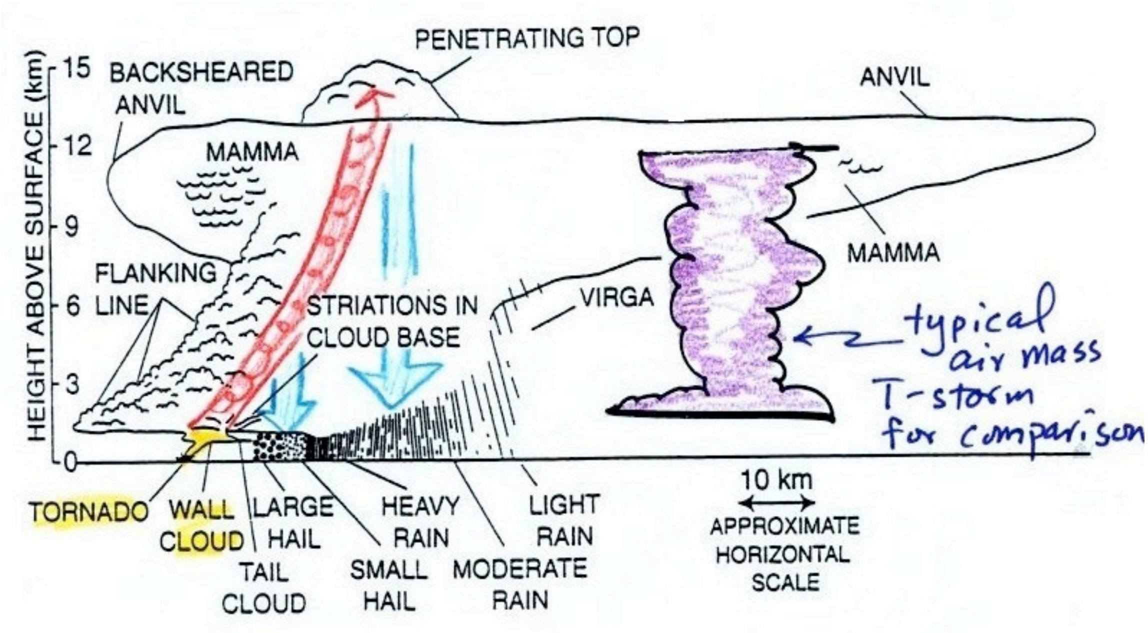
At right, the rising air is moving into the core of the rotating updraft where the pressure is lower than normal for this altitude. The air does not have to rise as high to experience the same amount of expansion and cooling. Consequently clouds form somewhat closer to the ground. We will see later that cooling and expansion also occurs when moist air moves horizontally into the low pressure core of a tornado.



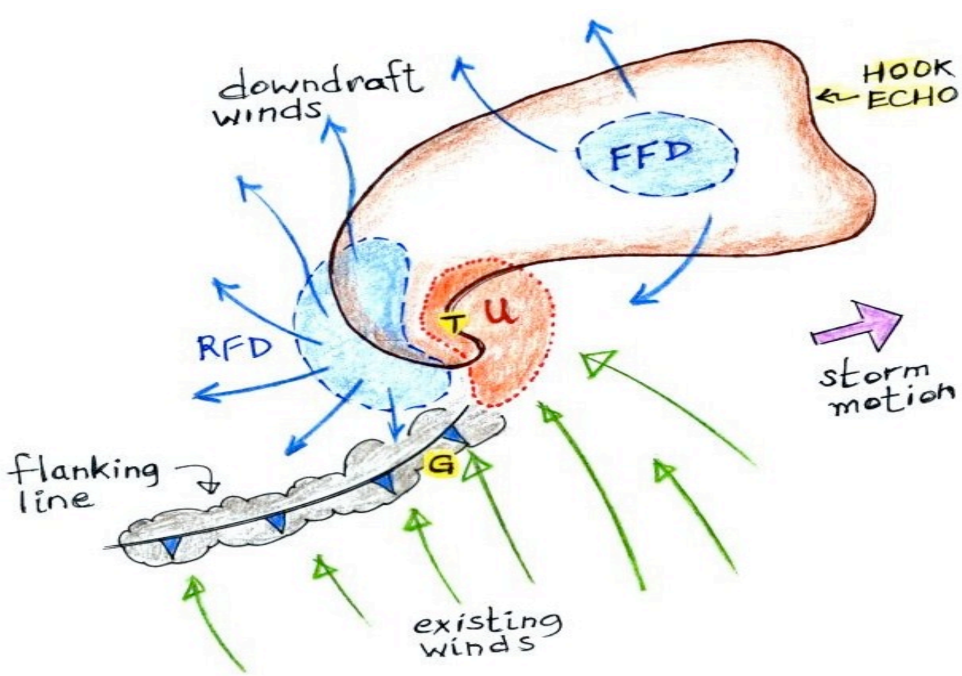
A severe thunderstorm that contains a mesocyclone is called a **supercell thunderstorm**. Here is is a simplified drawing of a supercell thunderstorm. The rotating updraft (shown in red below) is moving upward with enough momentum so that it penetrates a small distance into the stratosphere which produces the overshooting top or dome feature. A wall cloud and a tornado are shown at the bottom of the mesocyclone. A line of new thunderstorm cells are starting to form along the flanking line, where downdraft winds collide with pre-existing winds, similar to the gust front of an air mass (simple) thunderstorm.



Here is a more detailed drawing of a supercell thunderstorm. A typical air mass thunderstorm (purple) has been drawn in to give you an idea of relative size.



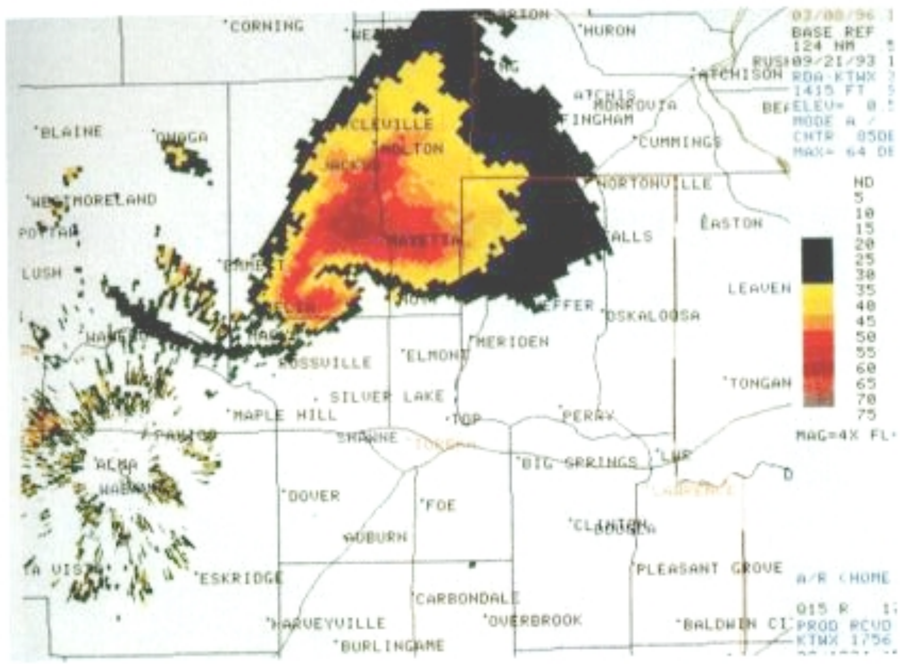
Thunderstorms with rotating updrafts often have a distinctive radar signature called a **hook echo**. A hook echo is sketched below (shaded in brown). Other thunderstorm features are also shaded; the front flant downdraft (FFD), the rear flank downdraft (RFD) and the rotating updraft (U). Tornato formation is more likely in the storm core and is indicated with a "T".



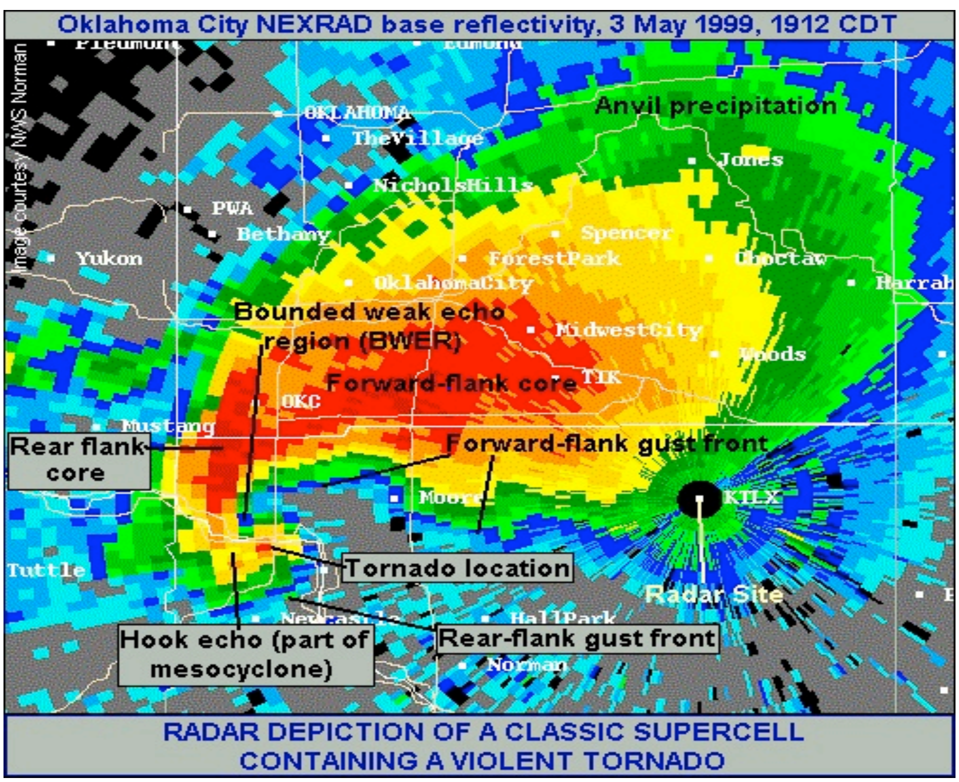
The cold front symbol has been used to show a gust front where existing winds collide with downdraft winds. This is the **flanking line**. Storm motion is toward the east to northeast. Someone interested in observing this storm (a "storm chaser") should position themselves southeast of the storm so that they would be able to view the wall cloud and any tornadoes that may form. Many of the interesting features would be hidden by rain if you were on the northwest side of the storm.

Along the flanking line or gust front (Point G) is a short-lived, low-level rotating cloud called a **gustnado** or gust front tornado. A gustnado lasts a few seconds to a few minutes and the winds are strong enough to cause some damage. These pictures of gustnados are from Wikipedia (http://en.wikipedia.org/wiki/Gustnado). The picture on the left was taken on October 4, 2002 in southeastern Wisconsin. The picture on the right was taken near Williamstown, Kansas on April 3, 2011. The Kansas gustnado caused damage similar to that of a weak tornado. "Two center pivot irrigations were flipped over, a large outdoor shed was destroyed and several tree limbs were snapped."


On the next page is an actual radar image of a supercell thunderstorm with a prominent hook echoe. Note that a portion of the flanking line is visible in this image. You cannot see the entire structure of the thunderstorm because the radar signal is reflected by precipitation particles but not by cloud droplets or ice crystals.

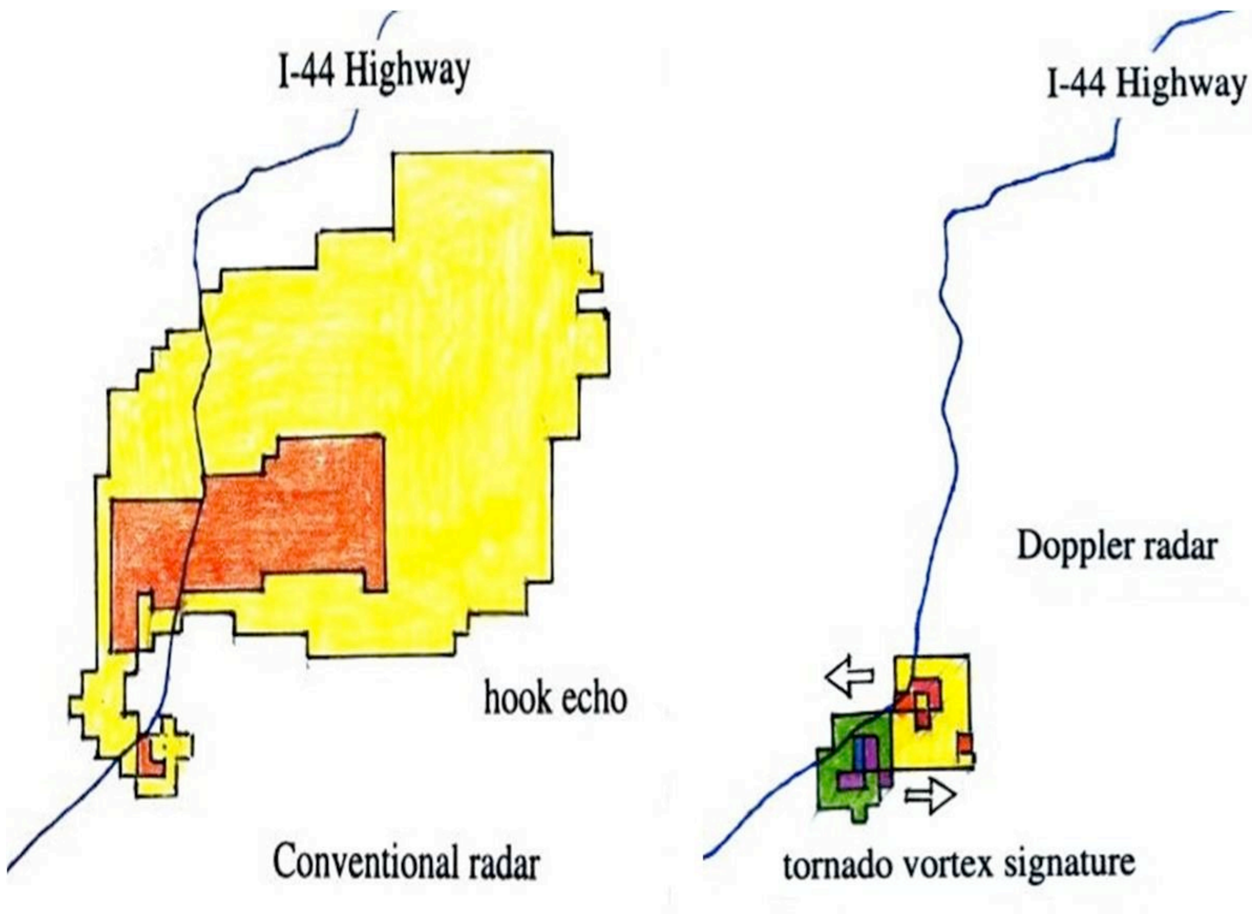


The radar image below is a May 3, 1999 storm that produced an F5 (perhaps an F6) tornado that hit Oklahoma City. Winds in the tornado may have exceeded 300 miles per hour at an altitude about 100 feet above the ground. Wind speeds were measured with a mobile doppler radar, which is discussed further on the next page.



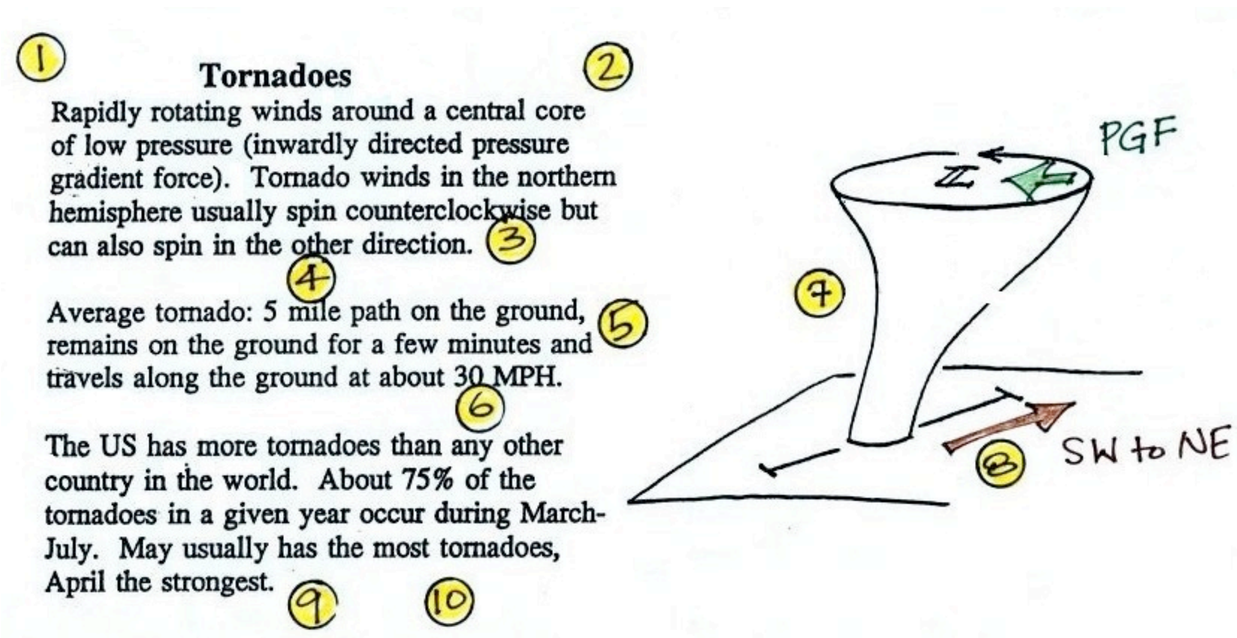
The hook echo shape obtained with conventional radar suggests that rotation could be occuring in a supercell thunderstorm. Doppler radar can confirm whether rotation is actually occuring. **Doppler radar** uses a shift in the frequency of the reflected signal to determine wind direction and speed. The sketches below are simplified images of a supercell thunderstorm obtained with both conventional and Doppler radar. The sketches are of the May 3, 1999 supercell storm.

The orange and yellow colors on the left image indicate the intensity of the reflected radar signal which is a function of the precipitation intensity. The Doppler image (right) indicates the wind direction and speed. The green, blue, and purple colors on the Doppler image show winds that are blowing toward the radar (the radar was east of the image). The red, orange, and yellow colors winds blowing away from the radar. The different colors correspond to different wind speeds. Winds blowing in opposite directions in such close proximity indicate rotation and are called a **velocity couplet or a tornado vortex signature**. In this case the winds are spinning in a counterclockwise direction. The Doppler radar is not able to detect the north and south components of the spin because those winds are not pointing toward or away from the radar.



Tornados

The drawing below describes some basic characteristics of tornados.



1. About two thirds of tornadoes are F0 or F1 tornadoes. The F refers to the Fujita scale which we will learn more about in Lecture 32. Tornados have spinning winds of about 100 miles per hour or less. Microburst winds can also reach 100 miles per hour. Tornados are rare in Tucson but Microbursts are fairly common. Microbursts can inflict the same level of damage as a tornado.

2. A very strong, inwardly directed pressure gradient force is needed to keep winds spinning in a circular path. The pressure in the center core of a tornado can be 100 mb less than the pressure in the air outside the tornado, a very large pressure difference over such a short distance. The pressure gradient is much stronger than the Coriolis force which can be neglected.

3. Tornadoes can spin clockwise or counterclockwise, although counterclockwise rotation is more common.

4. Tornadoes usually last only a few minutes, leave a path on the ground that is a few miles long, and travel at a speed of a few tens of miles per hour (Points 4-6 in the figure).

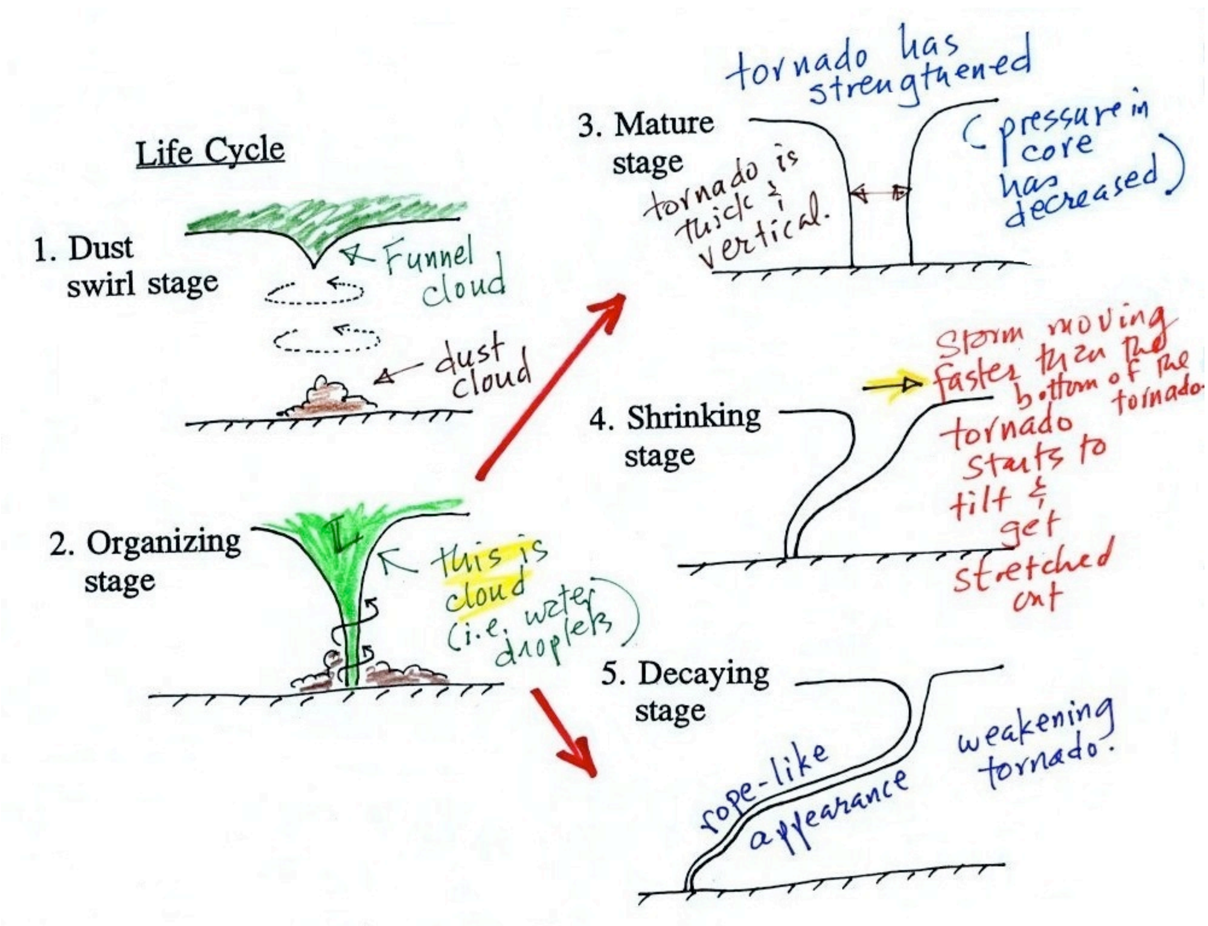
5. Most tornadoes move from the southwest towards the northeast because tornado-producing thunderstorms are often found just ahead of a cold front. Winds ahead of a cold front often blow from the southwest. Most tornadoes have diameters of tens to a few hundred yards but tornadoes with diameters over a mile have been observed (Points 7 and 8 in the figure).

6. Tornadoes are most frequent in the spring (Points 9 and 10 in the figure). The strongest tornadoes also occur at that time of year. Tornadoes are most common in the late afternoon when the atmosphere is most unstable.

The life cycle of a tornado is illustrated below. Tornadoes begin with a funnel cloud dropping from the base of a thunderstorm. The spinning winds become visible after they stir up dust at the ground level (Stage 1). The spinning winds may also be strong enough at this stage to cause minor damage. Here is a video of the beginning stages of a tornado: tornado in Laverne Oklahoma (http://www.youtube.com/watch?v=PmaRfFI3GUQ).

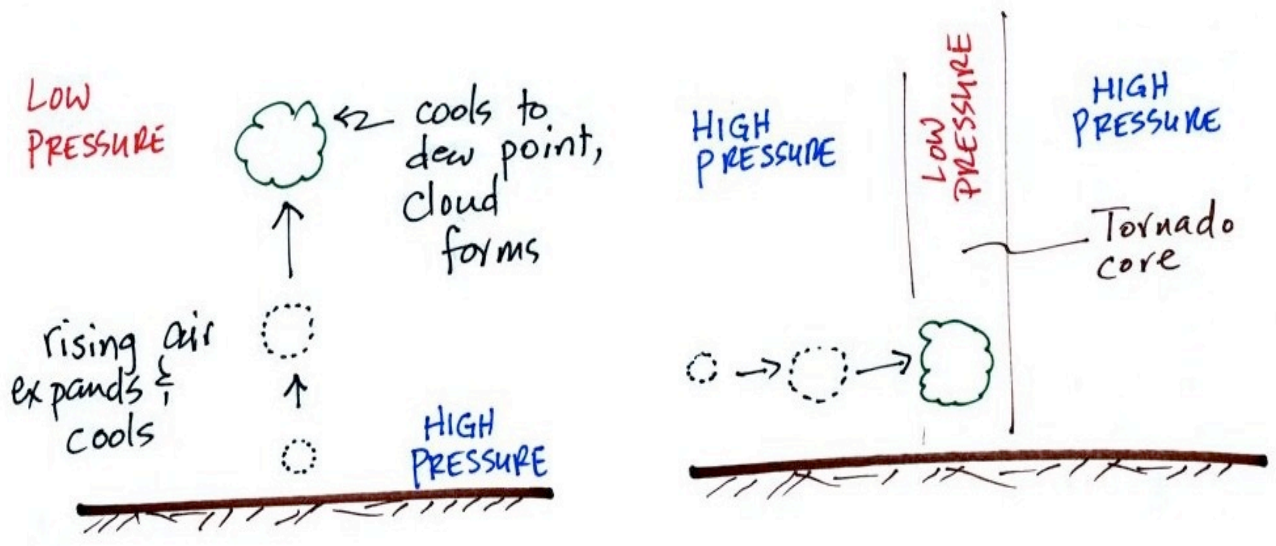
In Stage 2, moist air moves horizontally toward the low pressure core of the tornado. This sideways moving air will expand and cool in the same way that rising air does (see also the figure on the next page). Once the air cools to the dew point temperature, a cloud will form. The strongest tornadoes can go from Stage 2 to Stage 3 or directly from stage 2 to stage 5.

A strong tornado is usually vertical and thick as shown in Stage 3. "Wedge tornadoes" (http://www.chaseday.com/tornadoes.htm) actually appear wider than they are tall. The thunderstorm at the top of the tornado will move faster than the surface winds at the bottom of the tornado. This will tilt and stretch the tornado. The rope-like appearance in Stage 5 is usually a sign of a weakening (though still a dangerous) tornado.



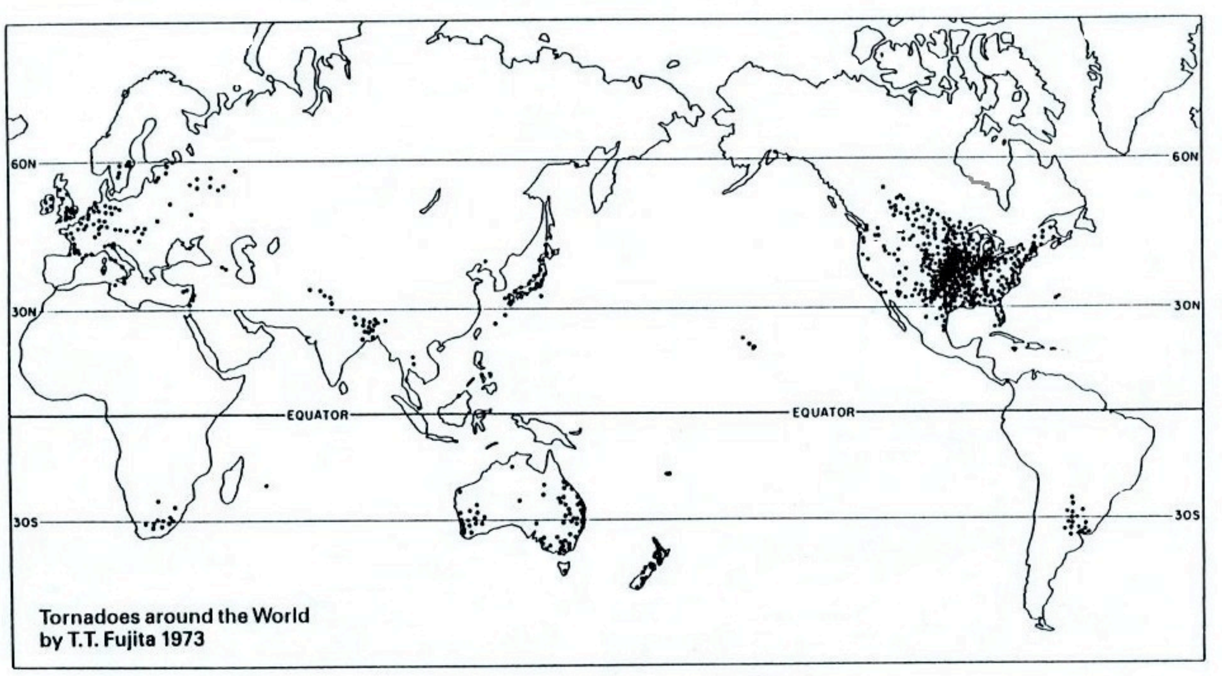
Life Cycle
1. Dust swirl stage
Funnel cloud
dust cloud
2. Organizing stage
this is cloud (i.e. water droplets)
3. Mature stage
tornado has strengthened
tornado is thick & vertical.
(pressure in core has decreased)
4. Shrinking stage
Storm moving faster than the bottom of the tornado
tornado starts to tilt & get stretched out
5. Decaying stage
rope-like appearance
weakening tornado.

A tornado cloud forms when moist air moves into the lower pressure core of the tornado, expands and cools to the dew point. This is same process that forms clouds when air rises into lower pressure areas.

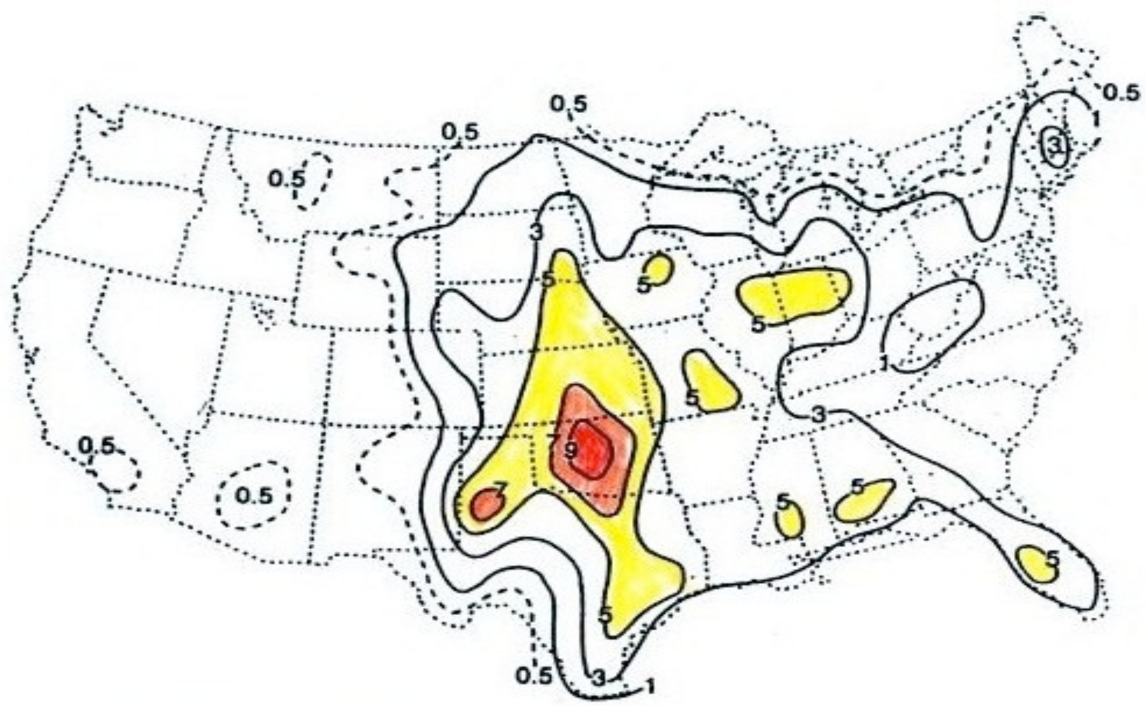


Below is a nice picture of a tornado extending downward from the bottom edge of a wall cloud (from the University Corporation for Atmospheric Research). This tornado was probably a relatively weak tornado.

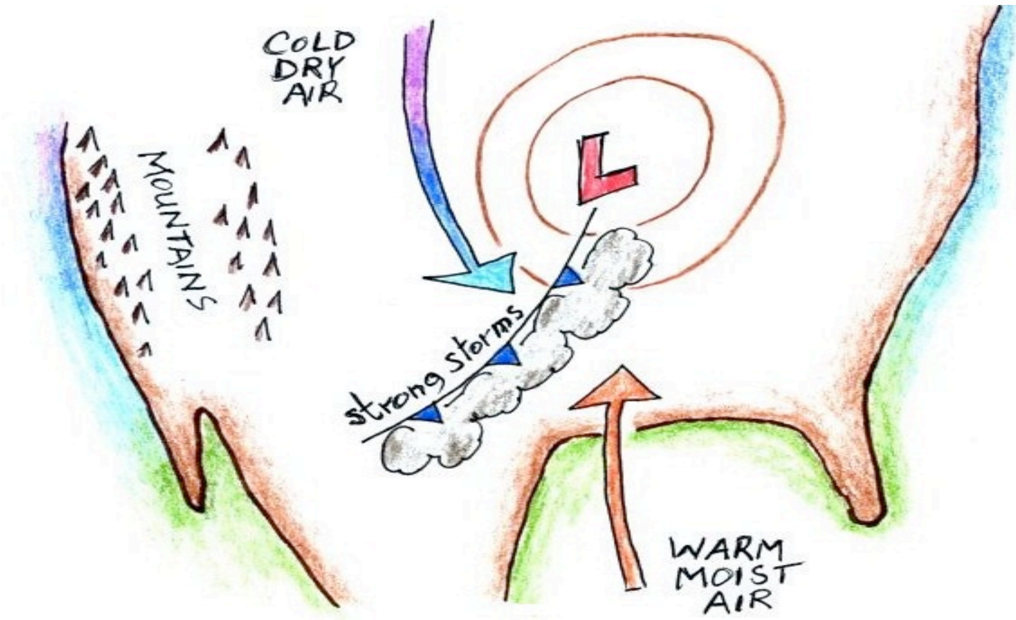
The United States has an average of about 1000 tornados a year, which is more than any other country in the world.



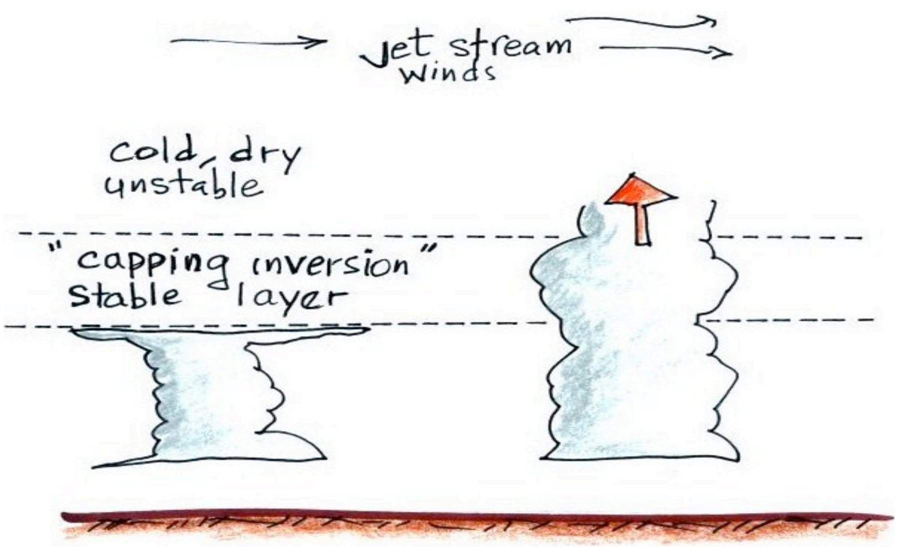
Tornadoes have been observed in every state in the US, but tornadoes occur most frequently in the central plains, a region referred to as "Tornado Alley" (highlighted in red, orange, and yellow below). The numbers are tornadoes per year within a circle of one degreee latitude by one degree longitude.



The central plains have just the right mix of meteorological conditions for tornado formation. (T. Fujita, "Tornadoes Around the World, Weatherwise, 26, 56-83, 1973). In the spring, cold dry air can move all the way from Canada to the Gulf Coast without being blocked by mountains. When the cold air front collides with warm moist air from the Gulf of Mexico, strong thunderstorms can form where the fronts meet.

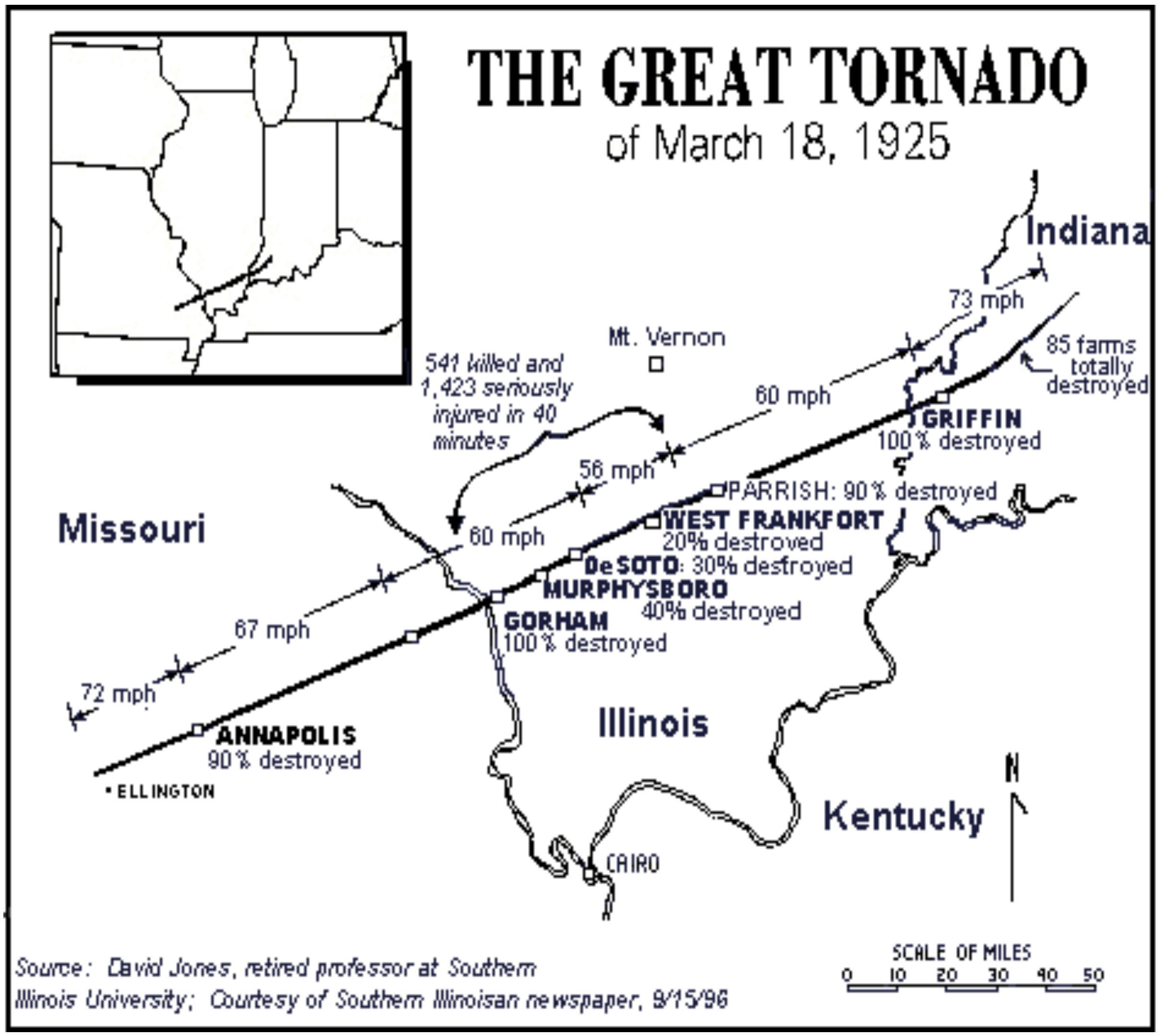


It seems counterintuitive, but a mid-level inversion layer can also contribute to severe thunderstorm development. An inversion layer tends to prevent relatively weak storms from forming. Instead only a few, stronger-than-average storms tend to form. If a strong storm is able to "punch through" the inversion layer, it encounters cold, dry and unstable air above that enable the storm to grow explosively. Jet stream winds overhead facilitate storm development by providing upper level divergence.

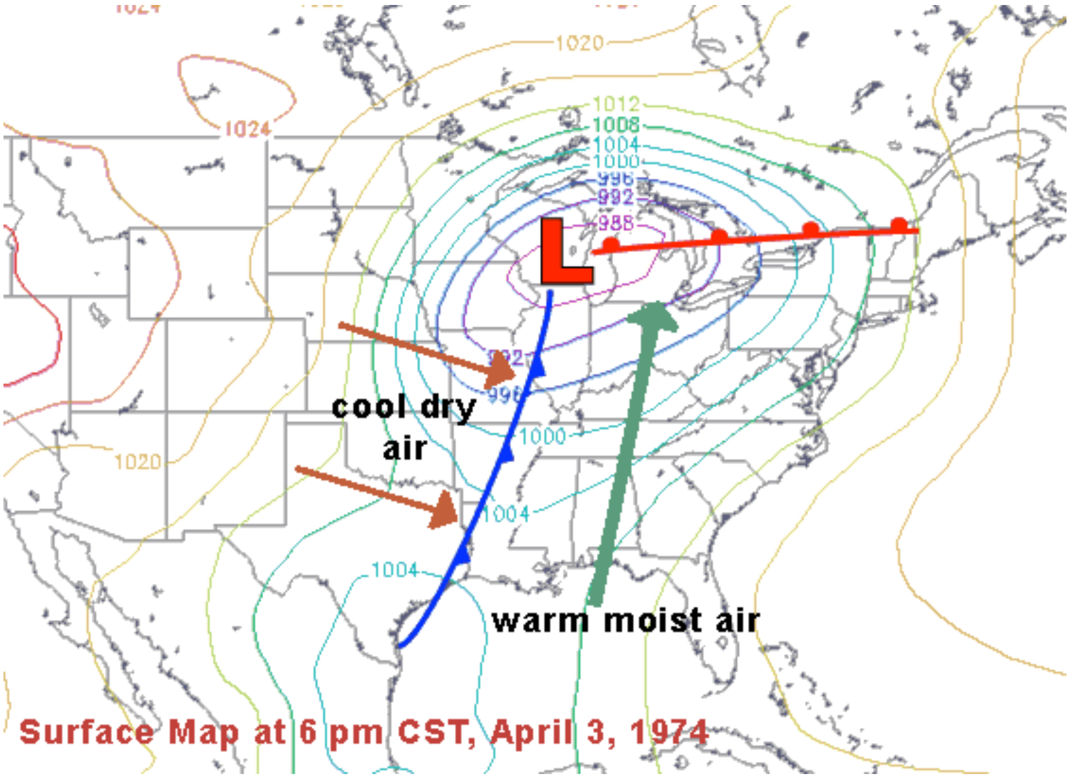


The figure below traces the path of the 1925 "Tri-State Tornado" (http://en.wikipedia.org/wiki/Tri-State_Tornado) the deadliest single tornado in United States history. The tornado path (note the southwest to northeast orientation) was 219 miles long. The tornado lasted about three and a half hours and killed 695 people. The tornado was traveling over 60 miles per hour over much of its path.

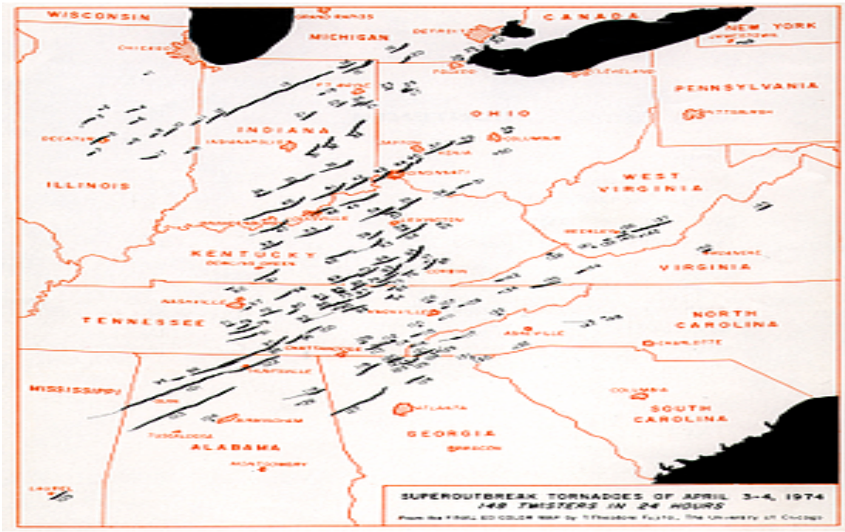
University of Arizona researcher Robert Maddox was part of the team that reconstructed the path of the Tri-State Tornado. The team interviewed survivors and analyzed paper records archived at the NOAA headquarters, Red Cross offices and various county courthouses. Amazingly, in 2005 there were still survivors of the tornado who were alive and vividly remembered their experiences.



Tornadoes often occur in clusters or "outbreaks". One hundred forty eight tornadoes were observed during the April 3-4, 1974 "Jumbo Tornado Outbreak" ()http://en.wikipedia.org/wiki/Super_Outbreak). The tornadoes were produced by thunderstorms forming along a cold front, as shown in the weather map below.



Here is a map of the 148 tornados that occured during the 1974 Jumbo Tornado Outbreak. Note that all the tornado paths have a SE toward NE orientation.



The recent [April 25-28, 2011 outbreak (http://en.wikipedia.org/wiki/April_25%E2%80%9328,_2011_tornado_outbreak)](http://en.wikipedia.org/wiki/April_25%E2%80%9328,_2011_tornado_outbreak) is now being called the largest tornado outbreak in US history. A total of 327 tornadoes in 21 states have been confirmed. At least 344 people were killed during the outbreak.

At the present time, tornadoes kill about 75 people every year in the United States. This is about a factor of ten less than a century ago due to improved methods of detecting tornadoes and severe thunderstorms. Modern day communications also make easier to warm people of dangerous weather situations. Lightning and flash floods (floods are the most serious severe weather hazard) kill slightly more people. Hurricanes kill fewer people on average than tornadoes.

Tornado Occurrence (per year)
century ago: <100
1950: 200
1953-1991: average 768
1990s: >1000

(both tables from ref 1)

↑ More people in tornado-prone regions

Tornado Deaths
1930s: 1945
1940s: 1786
1950s: 1419
1960s: 945
1970s: 998
1980s: 522
1990-
1996: 286

↑ Improved detection & warning