Ingredients for severe thunderstorms

INGREDIENT 1: CONDITIONAL INSTABILITY

Needs to be through the depth of the troposphere

Make the atmosphere more conditionally unstable by:
Warming and moistening near the surface
Cooling and drying aloft

INGREDIENT 2: WIND SHEAR

Change in horizontal wind speed through a vertical depth.

If the wind speed changes *direction* as well that's even better!

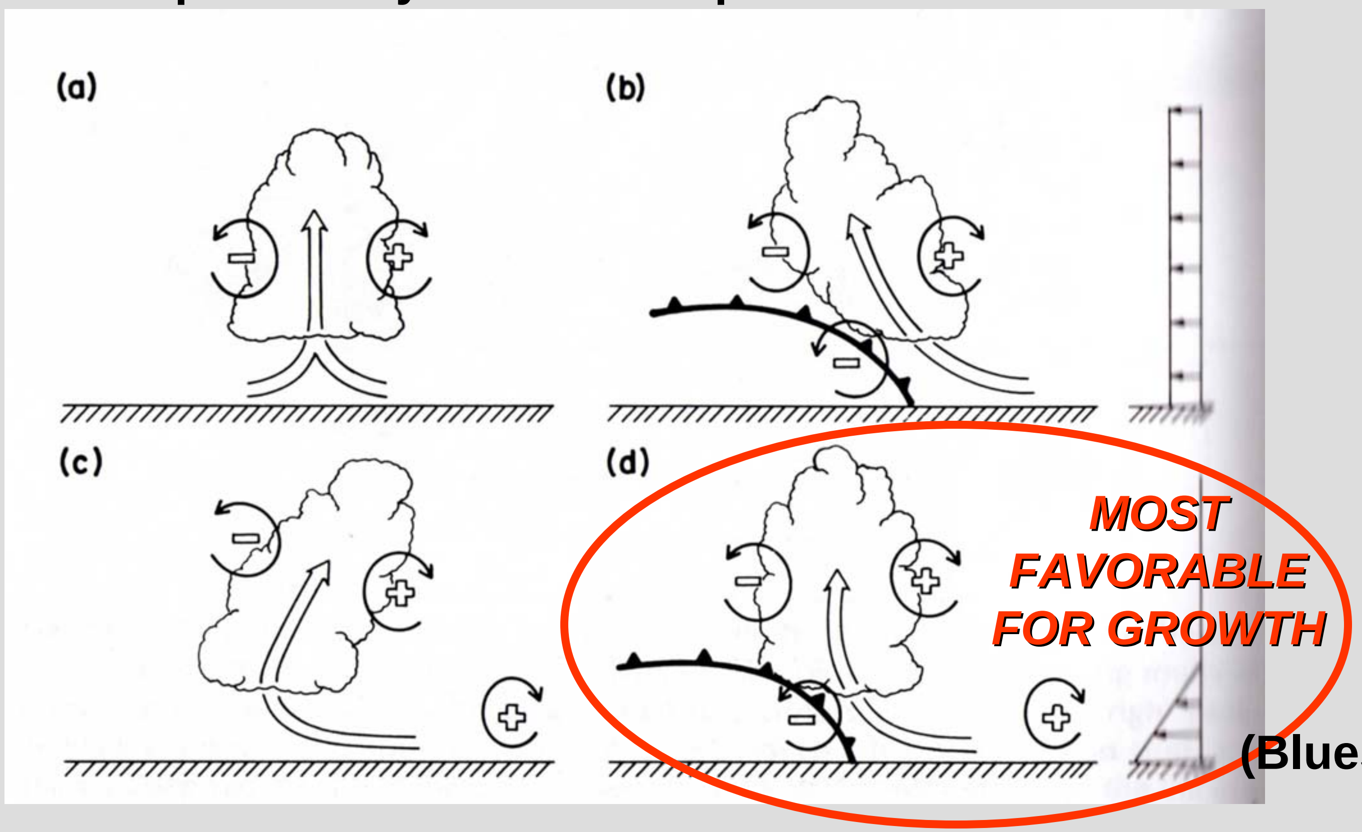
Why is wind shear a necessary ingredient for severe thunderstorms?

CUMULUS STAGE
Updraft only

MATURE STAGE
Updraft + downdraft

NO WIND SHEAR

WITH WIND SHEAR



(Bluestein)

Wind shear allows the updraft to be maintained in the cloud and not get choked off by the downdraft—so the thunderstorm keeps receiving the warm, moist air it needs to keep growing.

Where to look for severe thunderstorms (in central and eastern U.S.)

In the vicinity of a mid-latitude cyclone

Strong upper level winds from the north and west

Surface winds from the south to southeast (a low-level jet)

Fronts, particularly in front of and at a cold front in the warm sector

Drylines: transition zone between dry cT air and moist mT air

Very common in the southern Great Plains.

<u>THESE CAN ENHANCE</u>:

1. **THE VERTICAL WIND SHEAR**
2. **CONDITIONAL INSTABILITY (i.e. CAPE)**

More Organized Severe Thunderstorm Types

<u>In approximate order of severity</u>

Multicell thunderstorms

Squall lines

Mesoscale Convective Complexes

Supercells

Less severe

↓

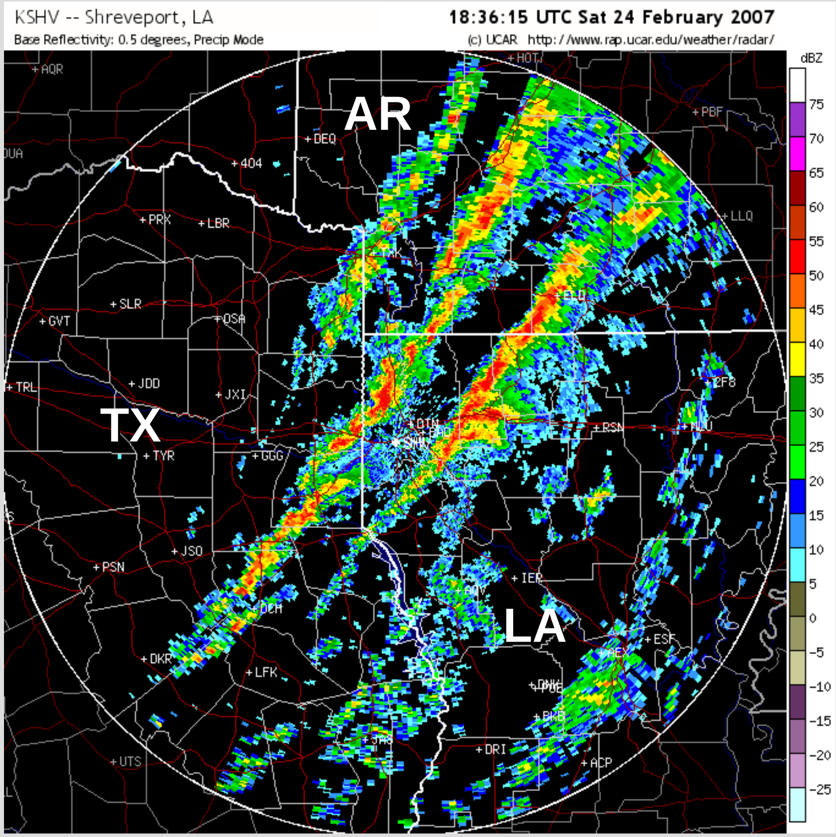
Most severe

Multicell Thunderstorms

In moderate shear, thunderstorms can get a bit more organized, numerous and have longer lifetimes.

Note the tilted structure of the anvil with respect to the cloud base—this indicates wind shear.

Squall Line



Squall lines on radar image in the warm sector of Colorado low. (February 2007 Case)

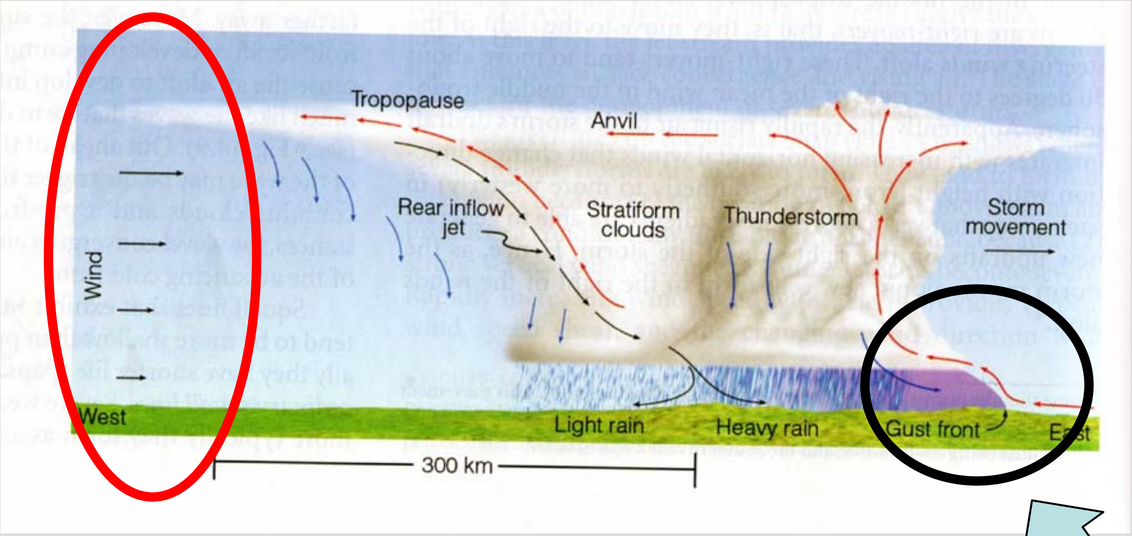
Line of thunderstorms that can be hundreds of miles long.

Form along the cold front or ahead of it in the warm sector

Heavy precipitation on the leading edge and then light rain behind.

Multiple lines may form, with the leading line being the most severe.

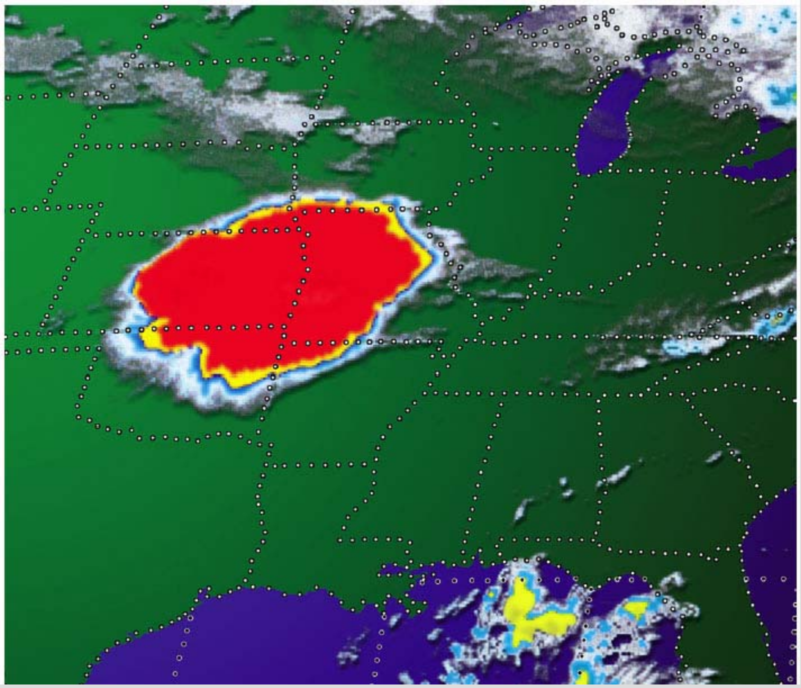
Idealized squall line thunderstorm structure



Note the wind shear profile

Shelf cloud at leading edge of squall line

Mesoscale Convective System (MCS)

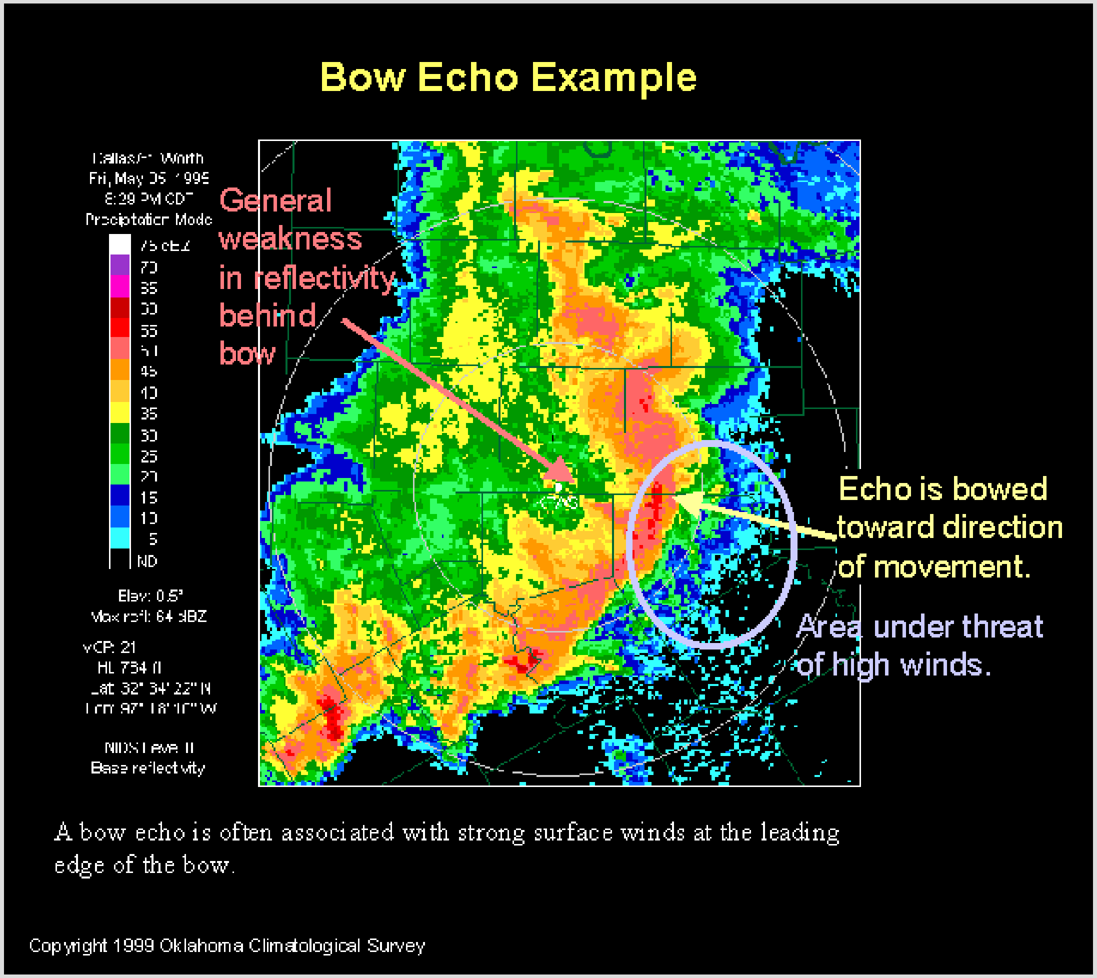


A number of individual thunderstorms cluster together to form a giant circular convective weather system.

Can be the size of an entire state!

Most common in summer, originating from convection which forms over mountains (the Rockies in the case of U.S.)

Derecho or Straight Line Wind



Bow echoes are typically found in well developed mesoscale convective complexes.

These produces very strong (straight line) winds which can potentially exceed hurricane force (75 mph).

Called a derecho (*Spanish = straight ahead*)

SUPERCELL

A BIG ISOLATED THUNDERSTORM THAT CONSISTS OF A ROTATING UPDRAFT.

THE MOST SEVERE TYPE OF THUNDERSTORM!

Ingredients for a supercell

INGREDIENT 1: HIGH "CAPE"

Make the atmosphere more conditionally unstable by:

Warming and moistening near the surface

Cooling and drying aloft

INGREDIENT 2: LARGE HELICITY

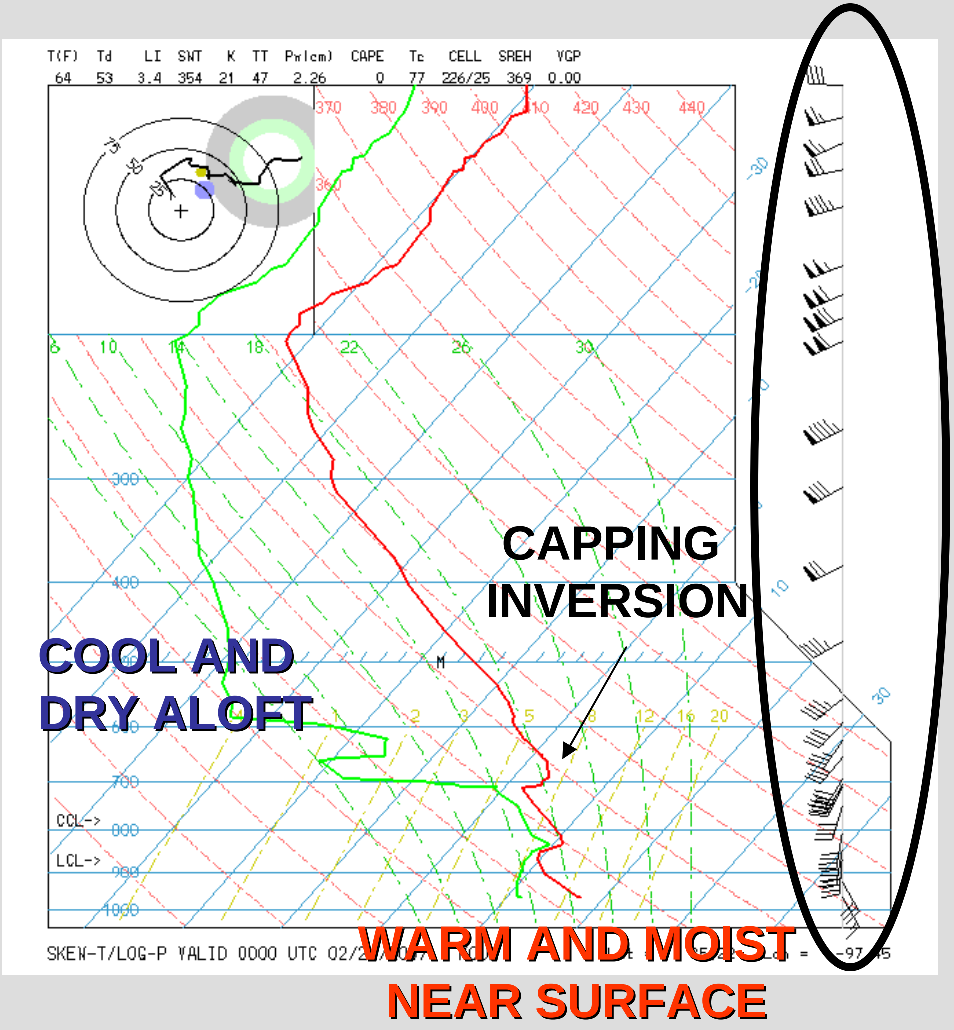
Helicity **is essentially the *wind shear*, or change in horizontal wind speed and direction, through a vertical depth.**

NECESSARY FOR THE STORM TO ROTATE!

(NEW) INGREDIENT 3: A CAPPING INVERSION

An inversion that occurs near about 800-mb. Only a few strong updrafts break through the cap and utilize the enormous amount of convective available potential energy

THE "LOADED GUN" SOUNDING
THE SIGNATURE FOR SUPERCELLS!



WIND DRASTICALLY CHANGES IN SPEED AND DIRECTION WITH HEIGHT

STORM SPLITTING PROCESS

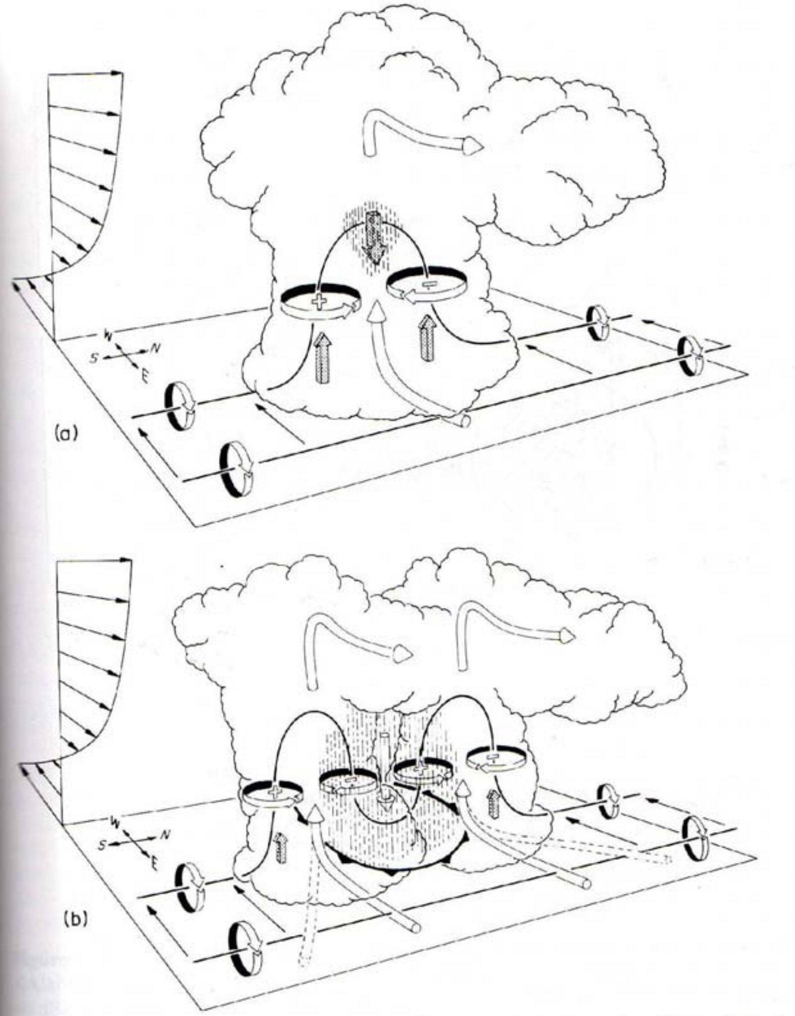


Figure 3.23 Schematic diagram depicting how a typical vortex line (streamline of three-dimensional vorticity vector) contained within (westerly) environmental shear is deformed as it interacts with a convective cell (viewed from the southeast). Direction of cloud-relative airflow (cylindrical arrows); vortex lines (solid lines), with the sense of rotation indicated by circular arrows; the forcing influences that promote new updraft and downdraft growth (shaded arrows); regions of precipitation (vertical dashed lines). (a) Initial stage: Vortex line loops into the vertical as it is swept into the updraft. (b) Splitting stage: Downdraft forming between the splitting updraft cells tilts vortex line downward, producing two vortex pairs. Boundary of the cold air spreading out beneath the storm (cold-front symbol at the surface) (from Klemp, 1987; adapted from Rotunno, 1981). (Courtesy of the American Meteorological Society)

Updraft rotates horizontal vorticity tubes into vertical. Precipitation and downdraft start to form.

Initial downdraft splits the storm in two separate storms, one that rotates cyclonically and the other that rotates anticyclonically.

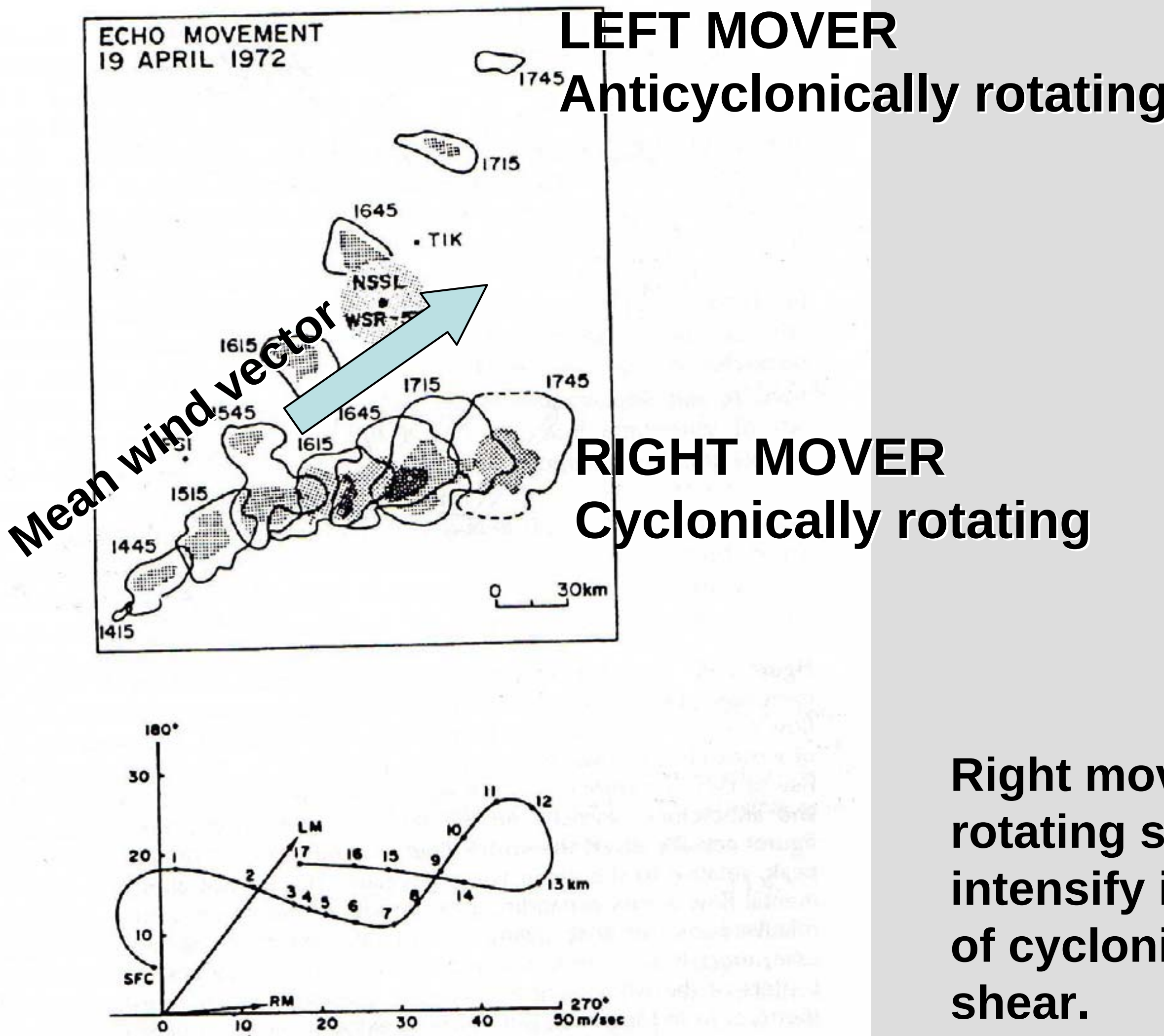
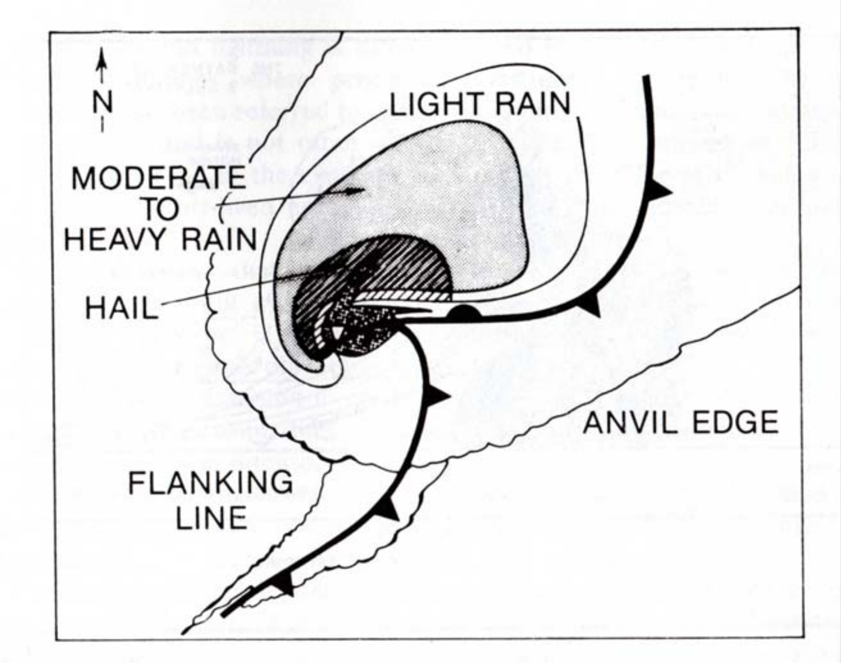


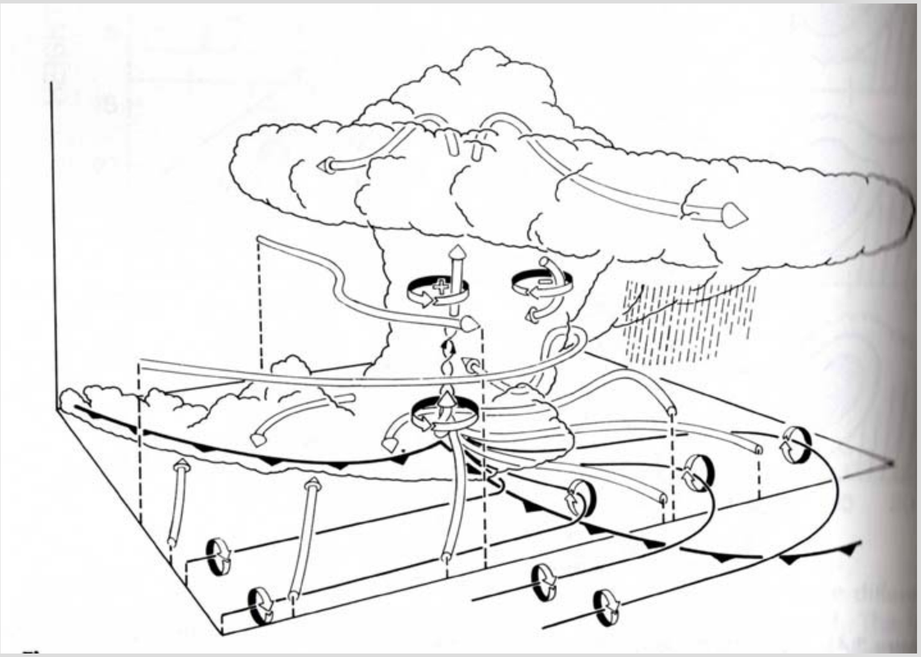
Figure 3.25 (Top) Radar-echo history of a splitting storm observed in south-central Oklahoma. Radar reflectivity of 10 dBZ (solid lines); radar reflectivity in excess of 40 dBZ (stippled regions). Times adjacent to each outline are CST. (Bottom) Hodograph representative of the storm's environment. Heights in km AGL. Motion of the right-moving (RM) and left-moving (LM) cells (from Weisman and Klemp, 1986; adapted from Burgess, 1974). (Courtesy of the American Meteorological Society)

Right moving, cyclonically rotating storm is favored to intensify in an atmospheric of cyclonically rotating wind shear.

Almost always the case in the central U.S.

Supercell structure

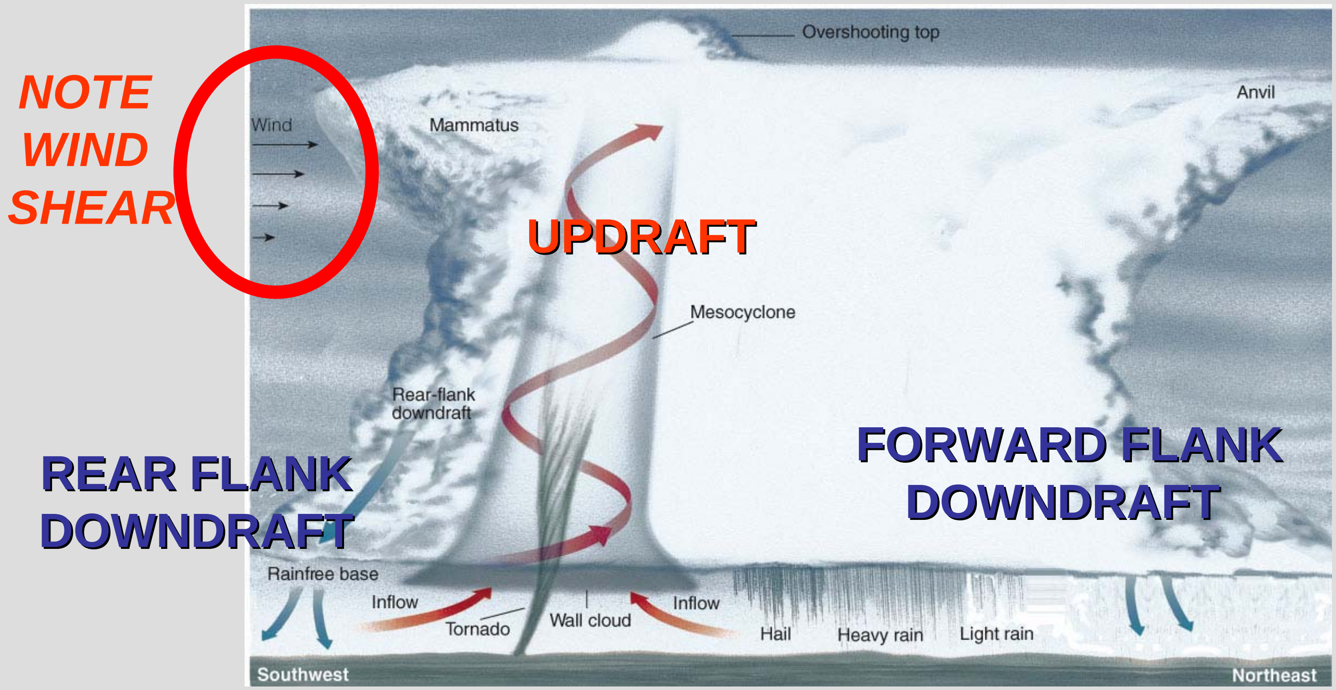




(Bluestein)

The fronts in this case indicate the gust fronts.

Vertical structure of tornadic supercell

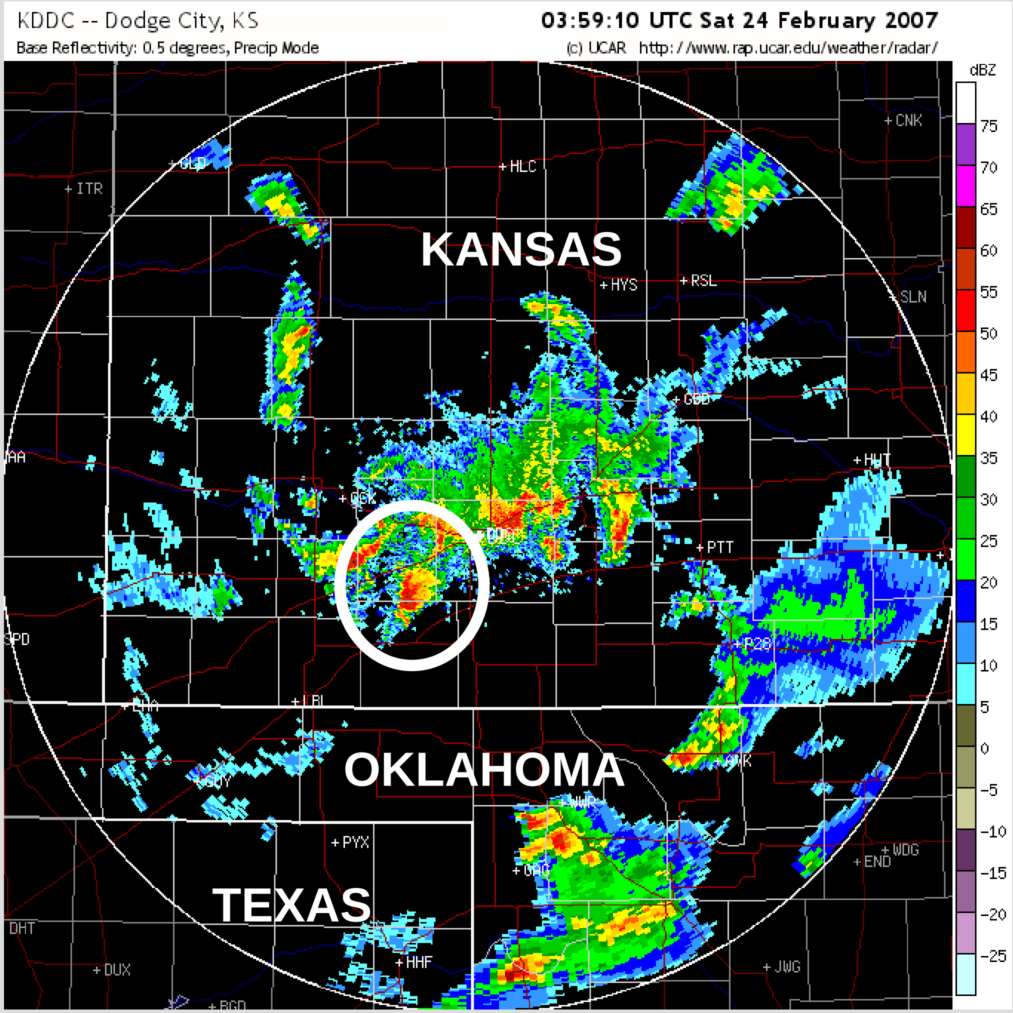


REAR FLANK DOWNDRAFT: Downdraft at the base of the supercell, right before the wall cloud.

UPDRAFT: Tornado forms at the base of the updraft is the extension of the mesocyclone, defined by a *wall cloud*.

FORWARD FLANK DOWNDRAFT: Precipitation falls in the form of (possibly large) hail and heavy rain.

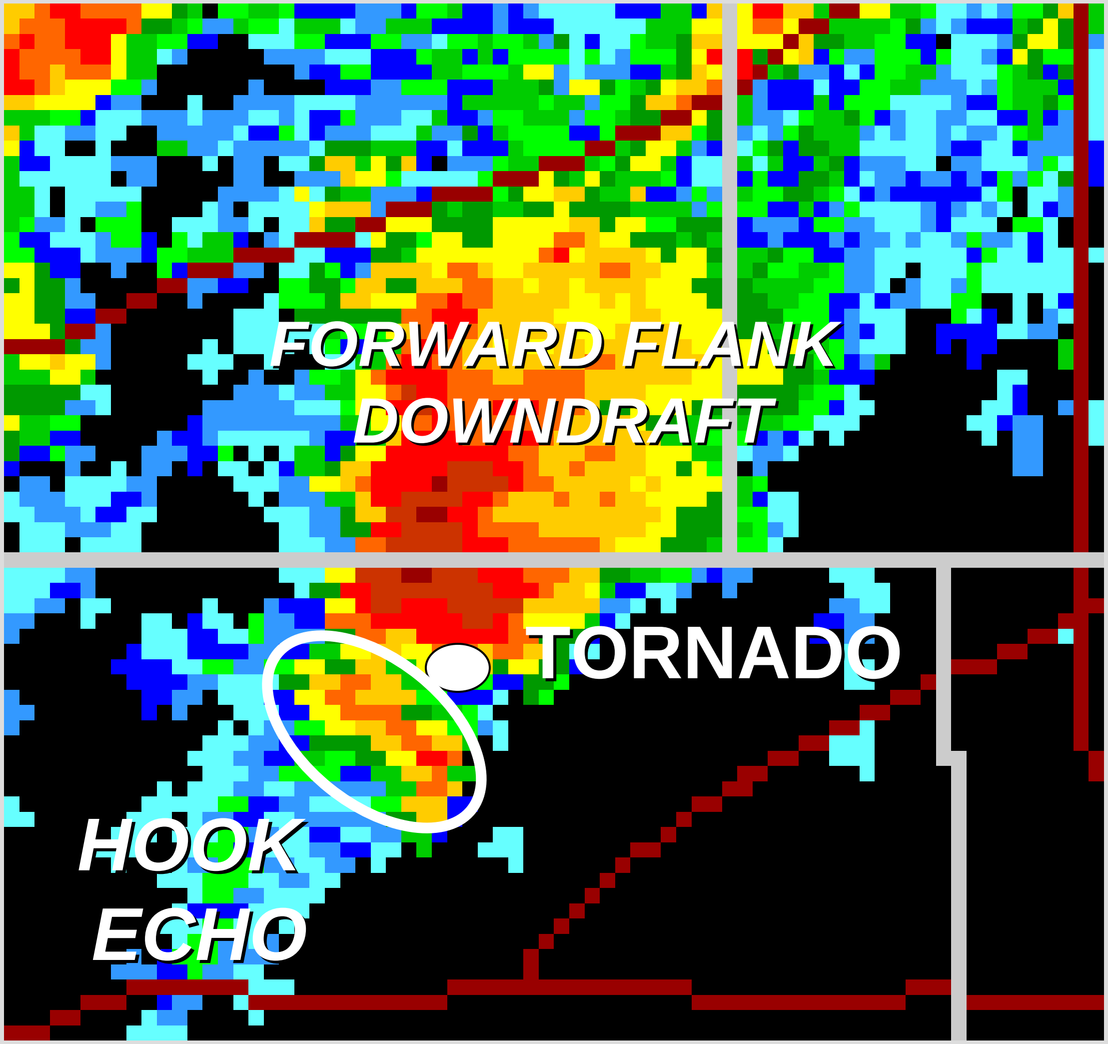
Supercells on radar



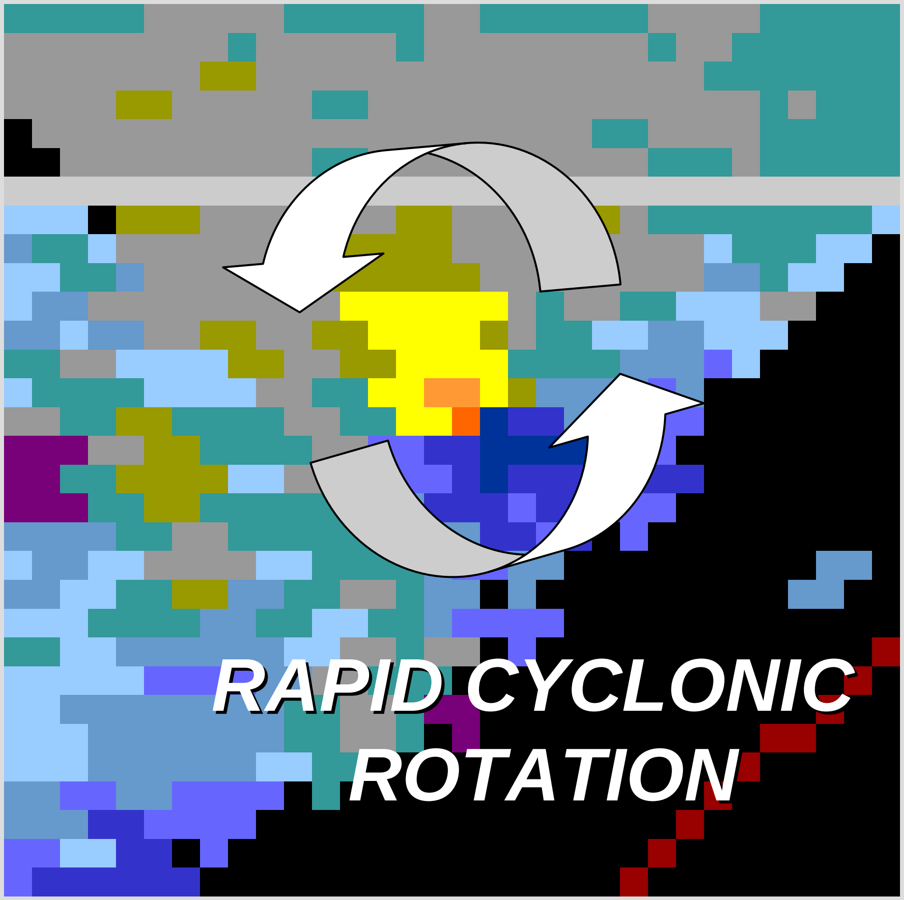
NOT big long squall lines!

Get compact and isolated rotating cells!

Radar signature of a tornadic supercell
Reflectivity



Radar signature of a tornadic supercell
Wind velocity



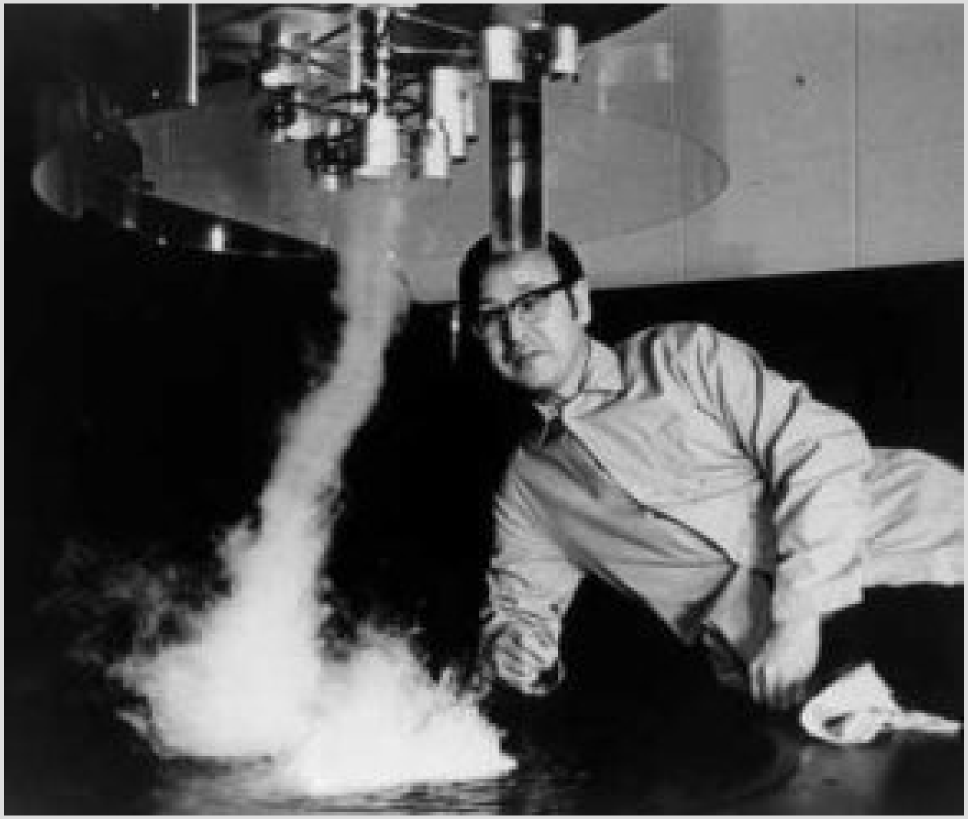
YELLOW = ECHOES TRAVELING AWAY FROM RADAR

BLUE = ECHOES TRAVELING TOWARD RADAR

NOTE: In Northern Hemisphere, tornadic supercells typically rotate counterclockwise due to the typical wind shear profile.

They can also rotate clockwise on rare occasions—since the vortex is in cyclostrophic balance.

Fujita Scale:
Gives a scale for tornado damage



Professor Ted Fujita

Now we use the Enhanced Fujita (EF) scale, which has slightly lower wind speed thresholds for the higher numbers than the original scale.

EF0: Very Weak

<u>Winds</u>: 65-85 mph

<u>Damage</u>: Broken tree branches and signs.

EF1: Weak

Miami, FL

<u>Winds</u>: 86-110 mph

<u>Damage</u>: Small trees snapped and windows broken

EF2: Strong

<u>Winds</u>: 111-135 mph

<u>Damage</u>: Large trees uprooted, weak structures destroyed

EF3: Very Strong

<u>Winds</u>: 136-165 mph

<u>Damage</u>: Severe; trees leveled, cars overturned, walls removed

EF4: Violent

<u>Winds</u>: 166-200 mph

<u>Damage</u>: Major devastation of sturdy structures.

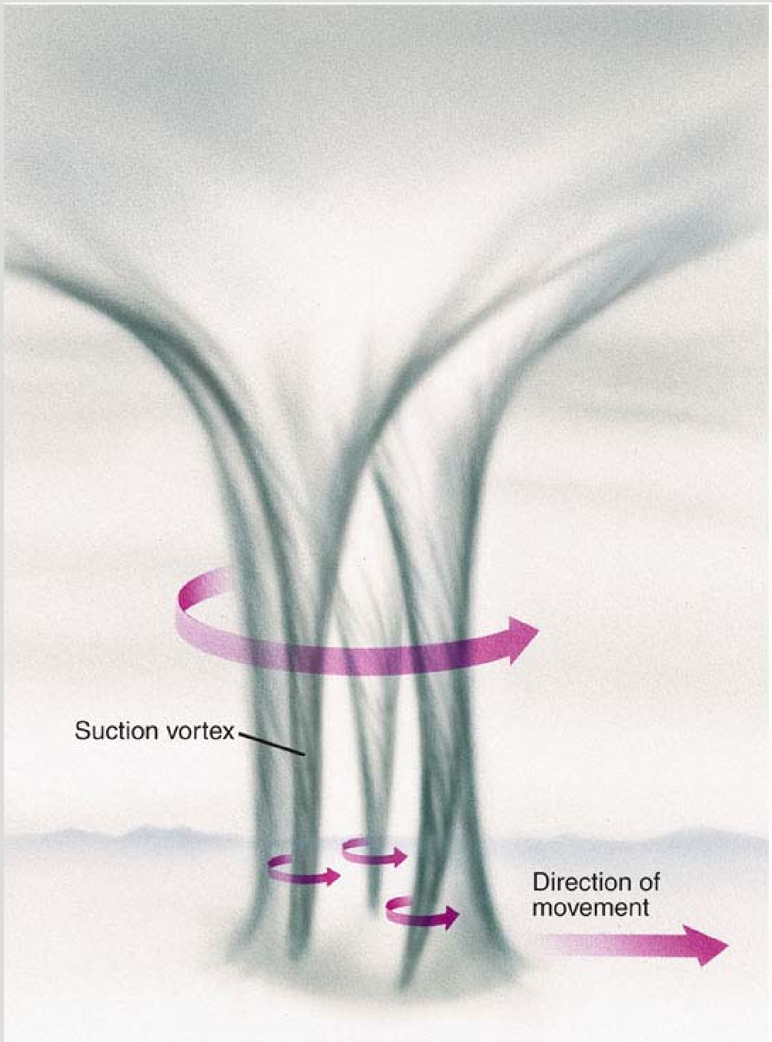
EF5: Catastrophic

Moore, OK
May 3, 1999

<u>Winds</u>: Over 200 mph

<u>Damage</u>: Ability to move major structures large distances (like houses, trucks, and cars). Total devastation!

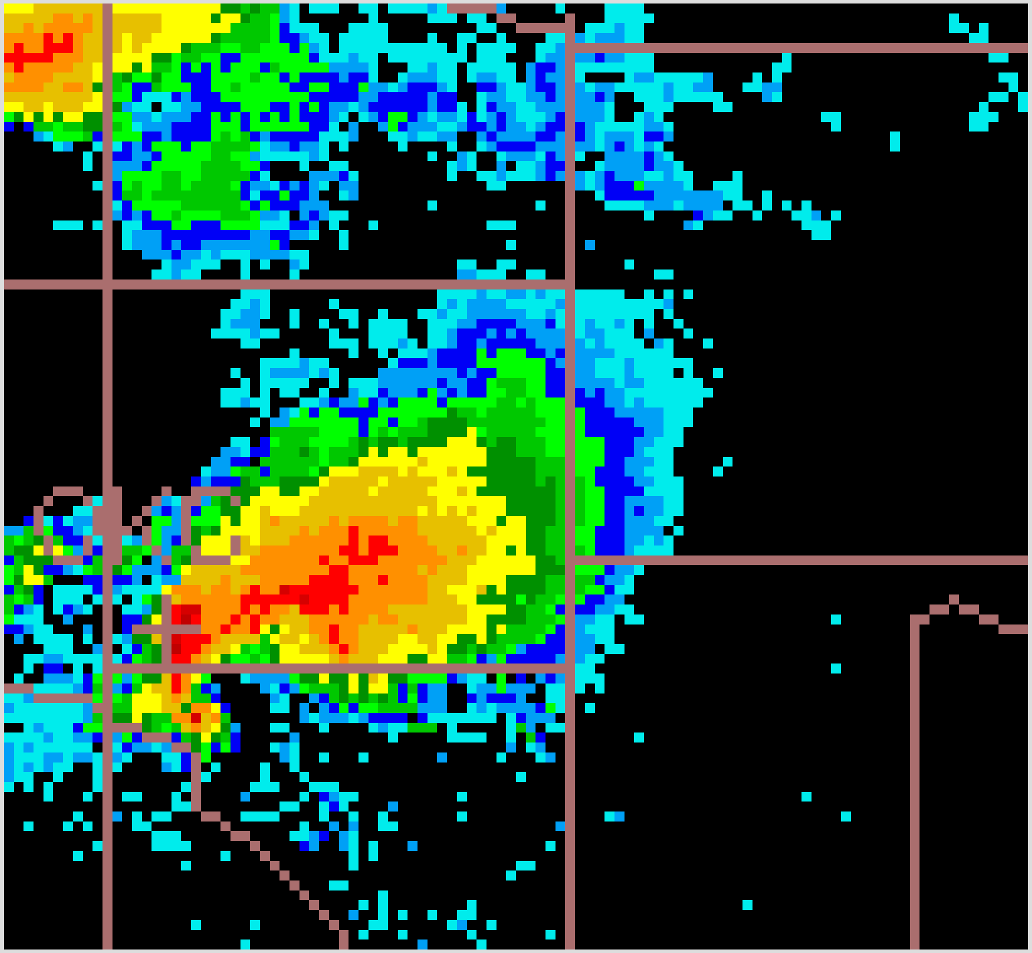
Suction Vortices



In the strongest tornadoes, small vortices within the main funnel with even higher wind speeds!

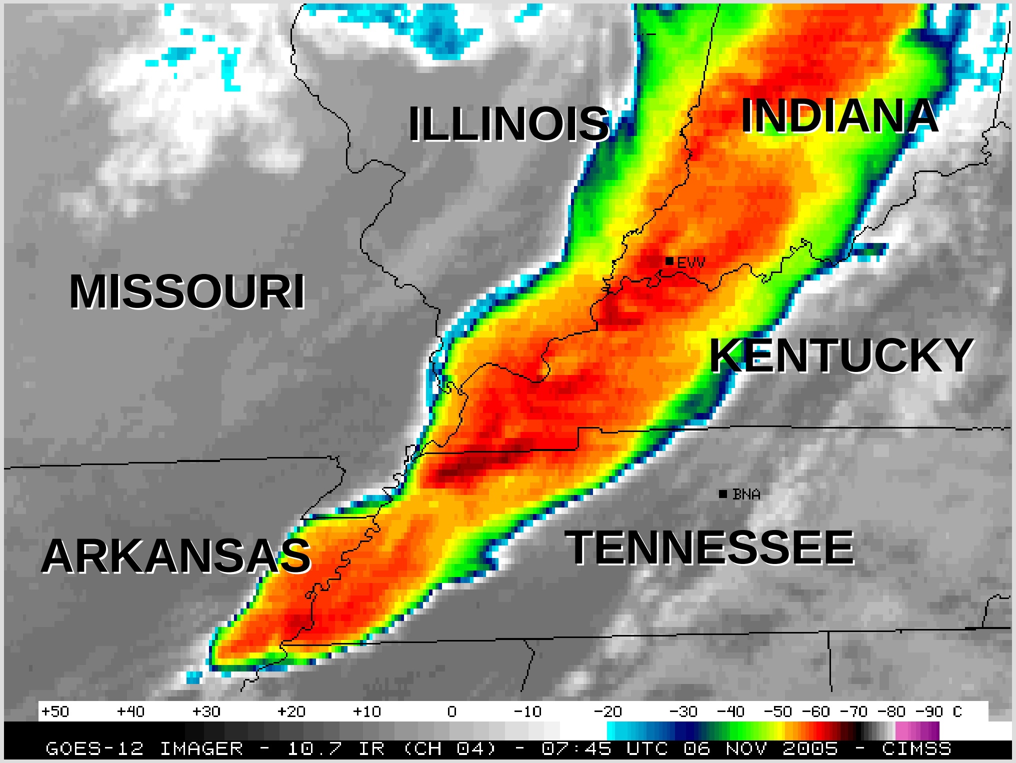
Moore, Oklahoma May 3, 1999

RADAR REFLECTIVITY



Meteorological Analysis
Sunday, Nov. 6, 2005

IR SATELLITE IMAGERY



(CIMMS, U. Wisc.)

A severe squall line along a cold front was moving through the lower Ohio River Valley.

National Weather Service in Paducah, KY, issued a severe thunderstorm watch.

Squall line broke down into supercell thunderstorms in the early morning hours after midnight.

Meteorological Analysis
Sunday, Nov. 6, 2005

EVANSVILLE, INDIANA

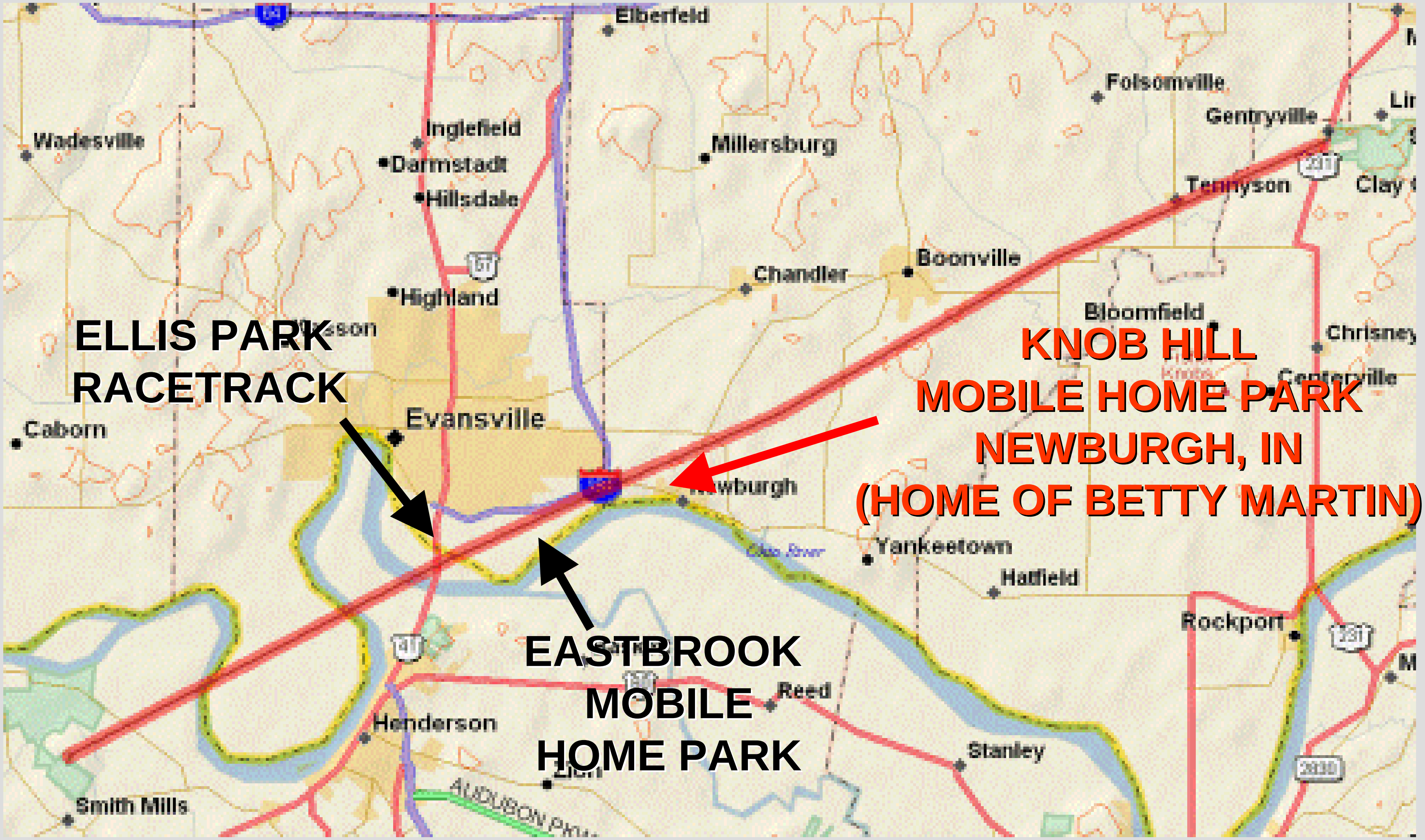
RADAR REFLECTIVITY

VIEW FROM DEACONESS HOSPITAL
DOWNTOWN EVANSVILLE

Before 2 AM, F3 tornado touched down near Smith Mills, Kentucky.

Several minutes later, the storm crossed the Ohio River and headed toward the east side of Evansville, Indiana.

Evansville Tornado Path



Ellis Park Racetrack

Tornado path after Ellis Park

Note the irregular pattern of torn up land—an indicator of the suction vortices within the tornado.

Eastbrook Mobile Home Park

About 20 people died here because of inadequate shelter and the fact the storm hit at 2 AM.

Eastbrook: Arial View of Tornado Path

These residents of this house lived to tell the tale…

Residents of this house in Warrick County, Indiana, survived by seeking shelter in the interior bathroom.

That was the only room left standing!

Greensburg, Kansas
Wiped off the map May 4, 2007.