A more detailed and quantitative consideration of organized convection: Part IV

Supercell Tornadoes

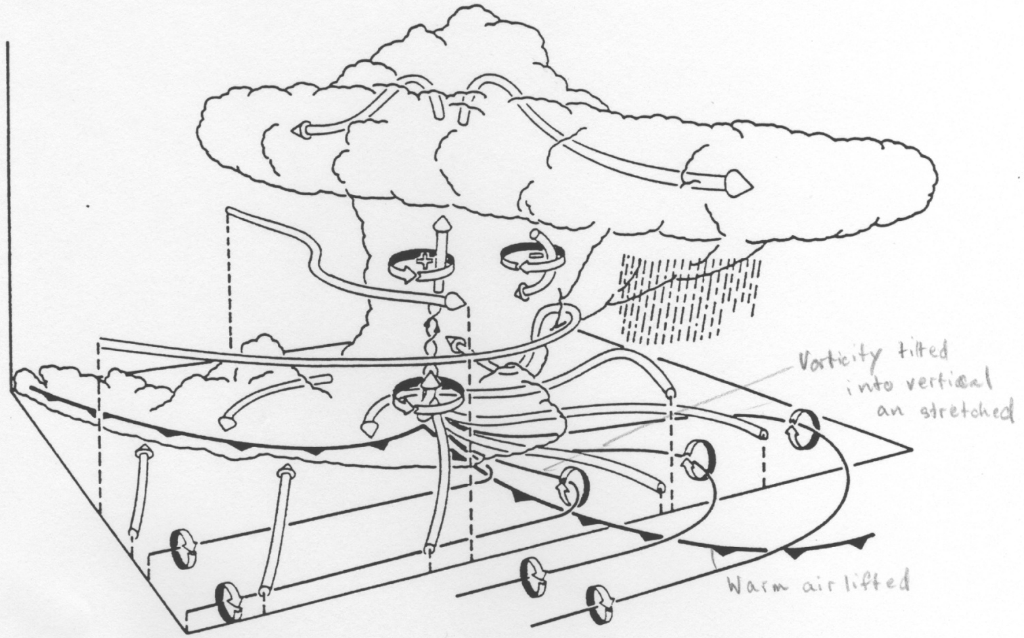
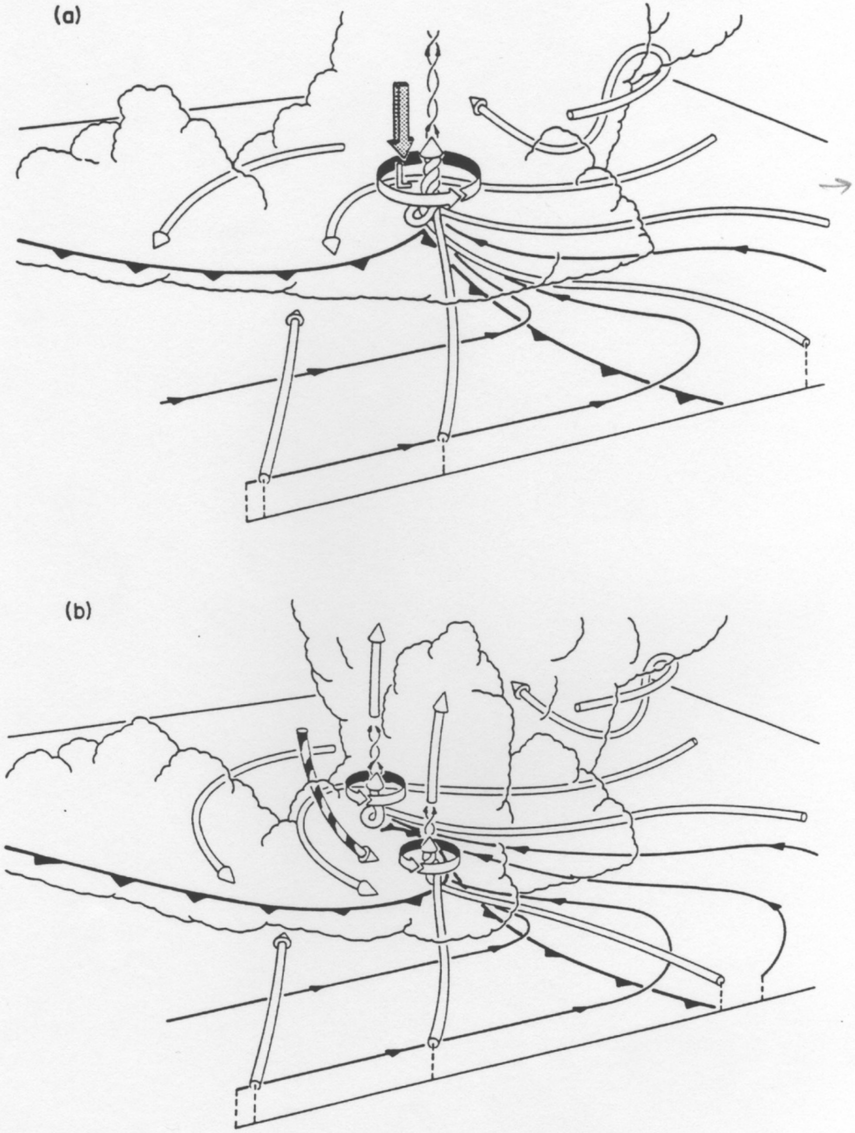


Figure 12 Three-dimensional schematic view of a numerically simulated supercell thunderstorm at a stage when the low-level rotation is intensifying. The storm is evolving in westerly environmental wind shear and is viewed from the southeast. The cylindrical arrows depict the flow in and around the storm. The thin lines show the low-level vortex lines, with the sense of rotation indicated by the circular-ribbon arrows. The heavy barbed line marks the boundary of the cold air beneath the storm.

Tornadogenesis preceded by the development of RFD and FFD. There is additional generation of horizontal vorticity along the edge of the cold pool in FFD.

A strong updraft tilts the horizontal vorticity into the vertical and stretches it



→ Circulation intensifies and creates sfc. low.

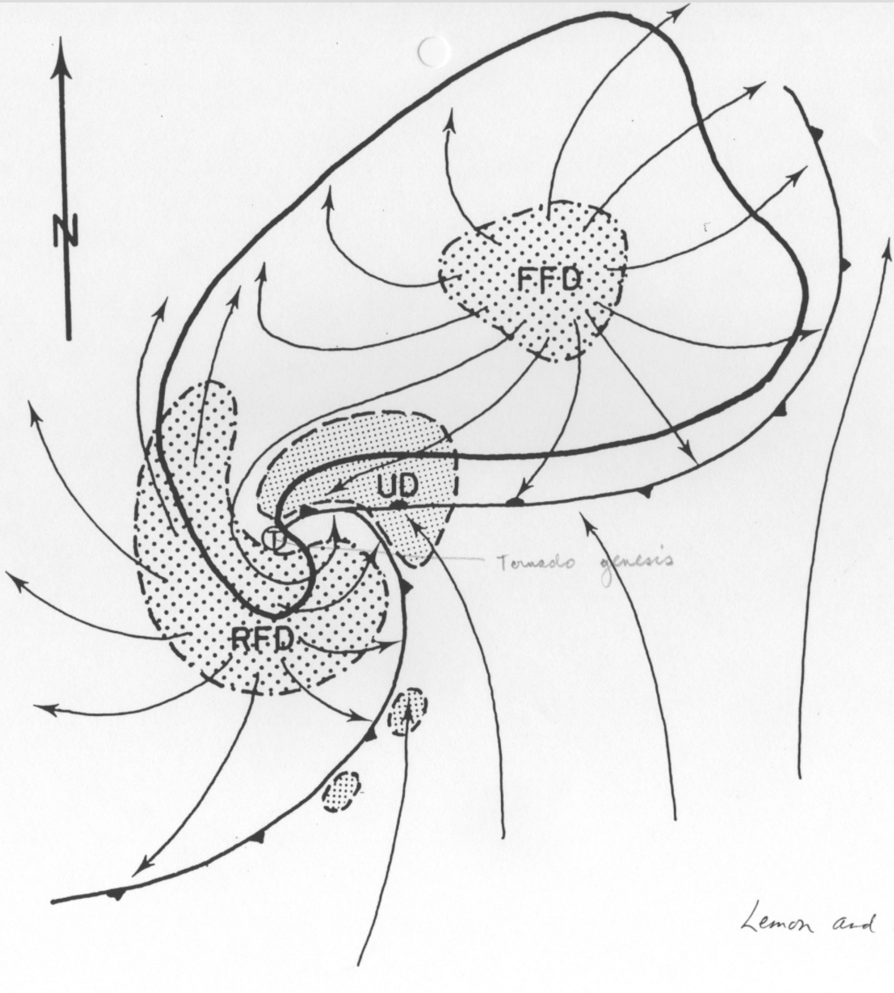
Figure 13 Expanded three-dimensional perspective, viewed from the southeast, of the low-level flow (*a*) at the time depicted in Figure 12, and (*b*) about 10 min later after the rear-flank downdraft has intensified. Features are drawn as described in Figure 12 except that the vector direction of vortex lines are indicated by arrows along the lines. The shaded arrow in (*a*) represents the rotationally induced vertical pressure gradient, and the striped arrow in (*b*) denotes the rear-flank downdraft.

The formation of the RFD is due to a downward directed perturbation pressure gradient due to the rapidly decreasing surface pressure.

The tornado forms in the updraft in front of the gust front of the RFD.

The exact trigger for what for the surface whirls that initiate tornado formation is still not well known.

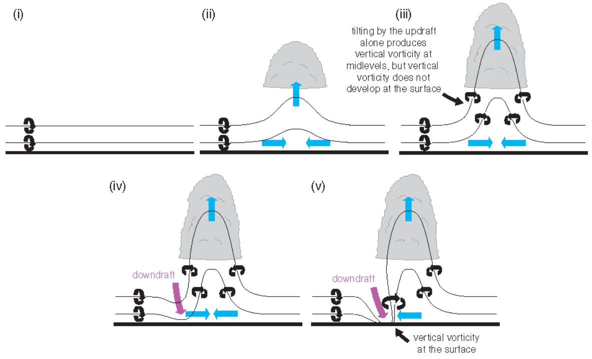
Surface inflows and outflows and vertical motions in mature tornadic supercell



Lemon and Doswell (1979)

How to induce the vertical velocity at the ground necessary for tornadogenesis?

(a) **vertical vorticity is initially negligible at the surface**



(b) **preexisting vertical vorticity at the surface**

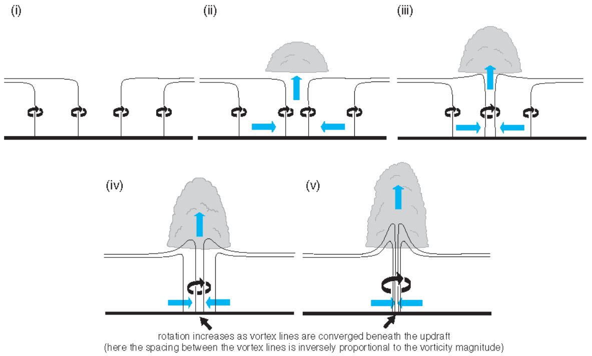


Figure 10.3 (a) Simple vortex line demonstration of why a downdraft is needed in order for significant vertical vorticity to develop at the ground beneath a thunderstorm in the absence of preexisting vertical vorticity at the surface. There is assumed to be no baroclinic vorticity generation; thus, the vortex lines are assumed to be frozen in the fluid. This is obviously an oversimplification, for there must be baroclinity at least somewhere or else a buoyant updraft could not exist in the first place (rainy downdrafts and their associated baroclinity, even if it is just a result of hydrometeor loading, are also a virtual certainty at least somewhere in the vicinity of a thunderstorm updraft). Nonetheless, the basic conclusion reached from considering only a purely barotropic redistribution is not changed: if tilting of vortex lines is accomplished by only an updraft, significant vertical vorticity cannot arise at the ground because air is rising away from the ground as it is tilted. On the other hand, if a downdraft is involved, a positive contribution to the vertical vorticity tendency can arise from tilting even as air is sinking toward the ground. (b) Simple vortex line demonstration of how a tornado can arise from convergence alone, in the absence of a downdraft, when preexisting vertical vorticity is present at the ground.

Possibility #1:

Outflow from RFD contributes to tilting of updraft

Possibility #2:

Local surface convergence, for example arising from frictional effects.

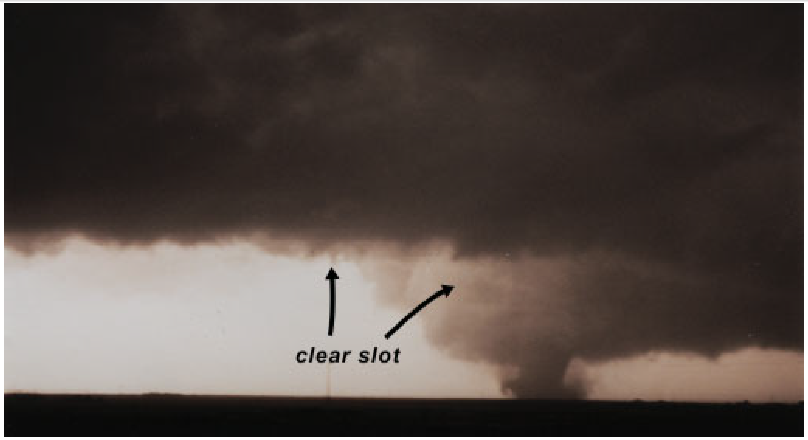


Figure 10.4 A clear slot like that shown above near the Dimmitt, TX, tornado on 2 June 1995 is a visual manifestation of sinking air, probably in what ought to be regarded as an *occlusion downdraft* (defined in Section 8.4 as a local, dynamically driven intensification of sinking motion within the larger-scale RFD). Photograph by Paul Markowski.

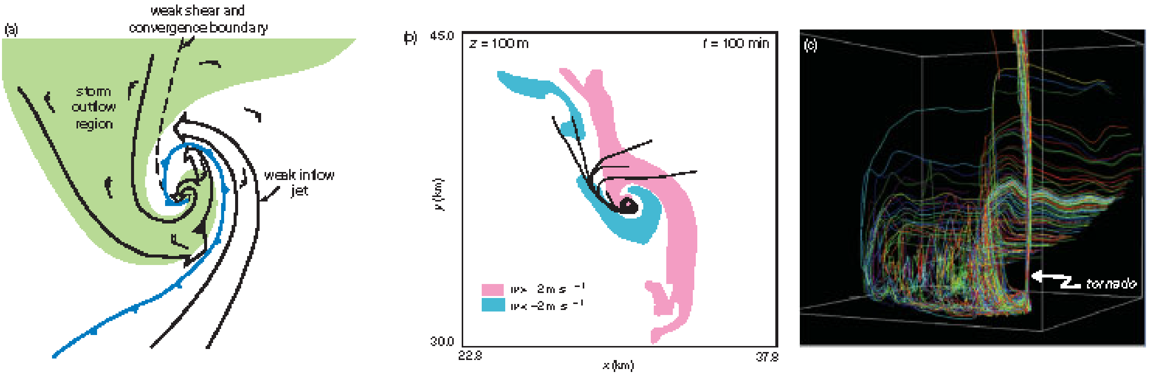
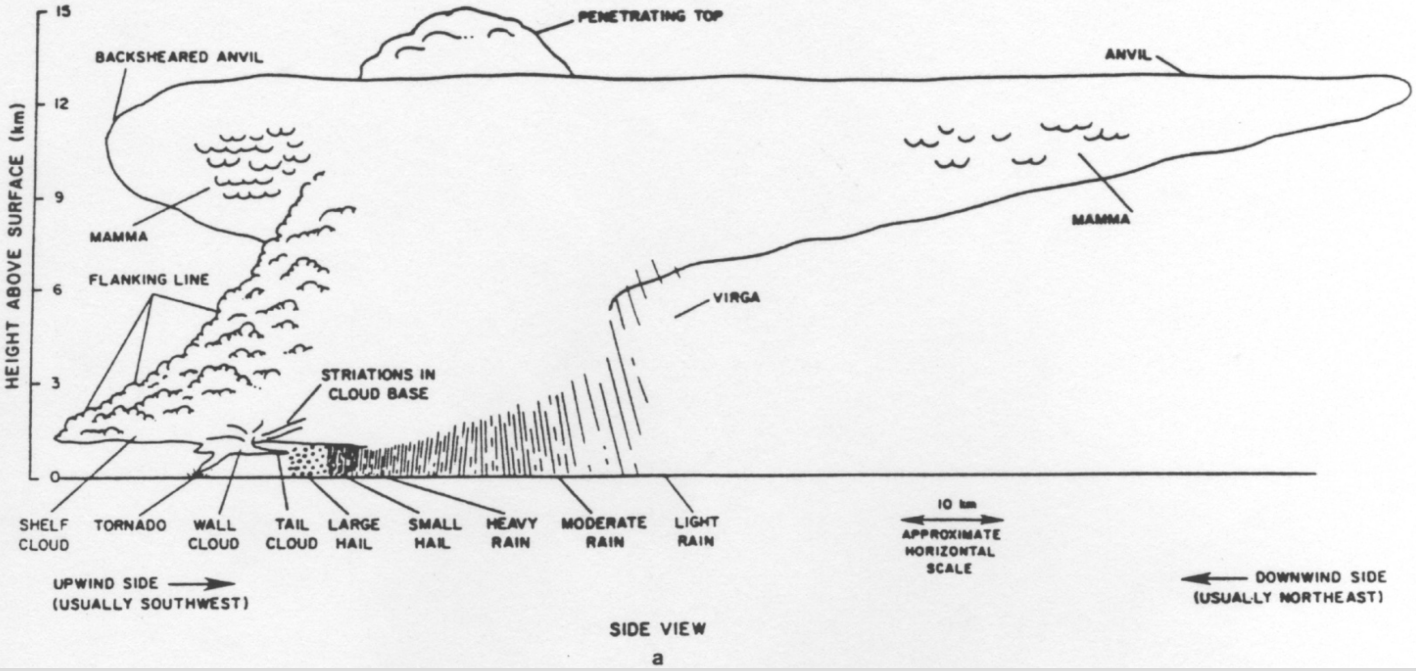
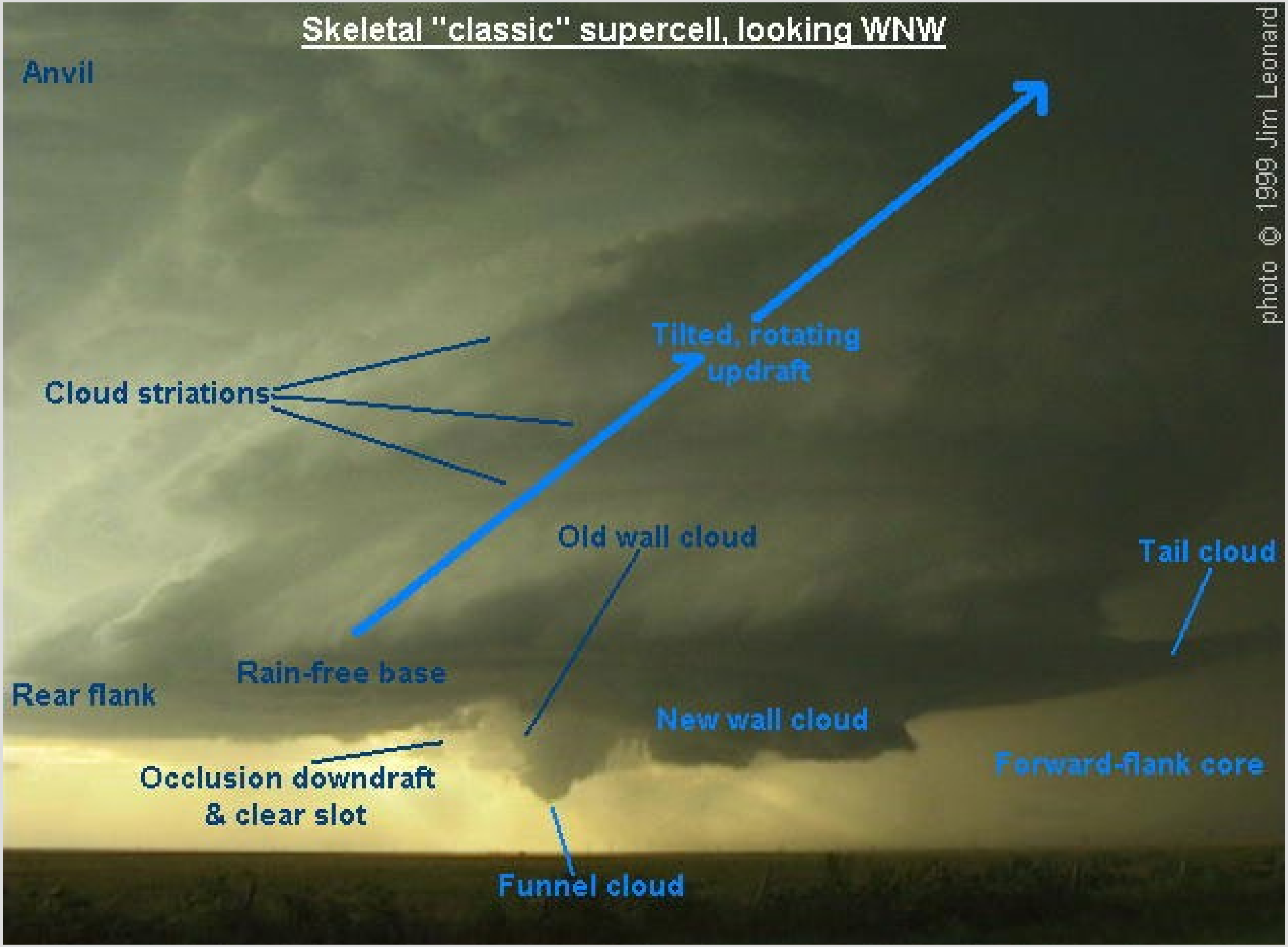


Figure 10.5 Observations and numerical simulations indicate that the air that enters tornadoes, tornado parent circulations, or nontornadic, near-ground circulations in supercells typically enters the circulations from the outflow air mass, rather than directly from the inflow. Such findings are consistent with the notion of downdrafts being important in the generation of rotation near the ground in supercells. (a) Trajectories in the RFD region composited from dual-Doppler observations of supercell thunderstorms (adapted from Brandes [1978]); (b) backward trajectories computed from the near-ground vertical vorticity maximum in a supercell simulation (adapted from Wicker and Wilhelmson [1995]); (c) a three-dimensional perspective from the southeast of trajectories entering a tornado that developed within a supercell simulation (from Xue [2004]; courtesy of Ming Xue).

Classic supercell: Form in high directional shear, high CAPE environments
Typical “Tornado Alley” storms

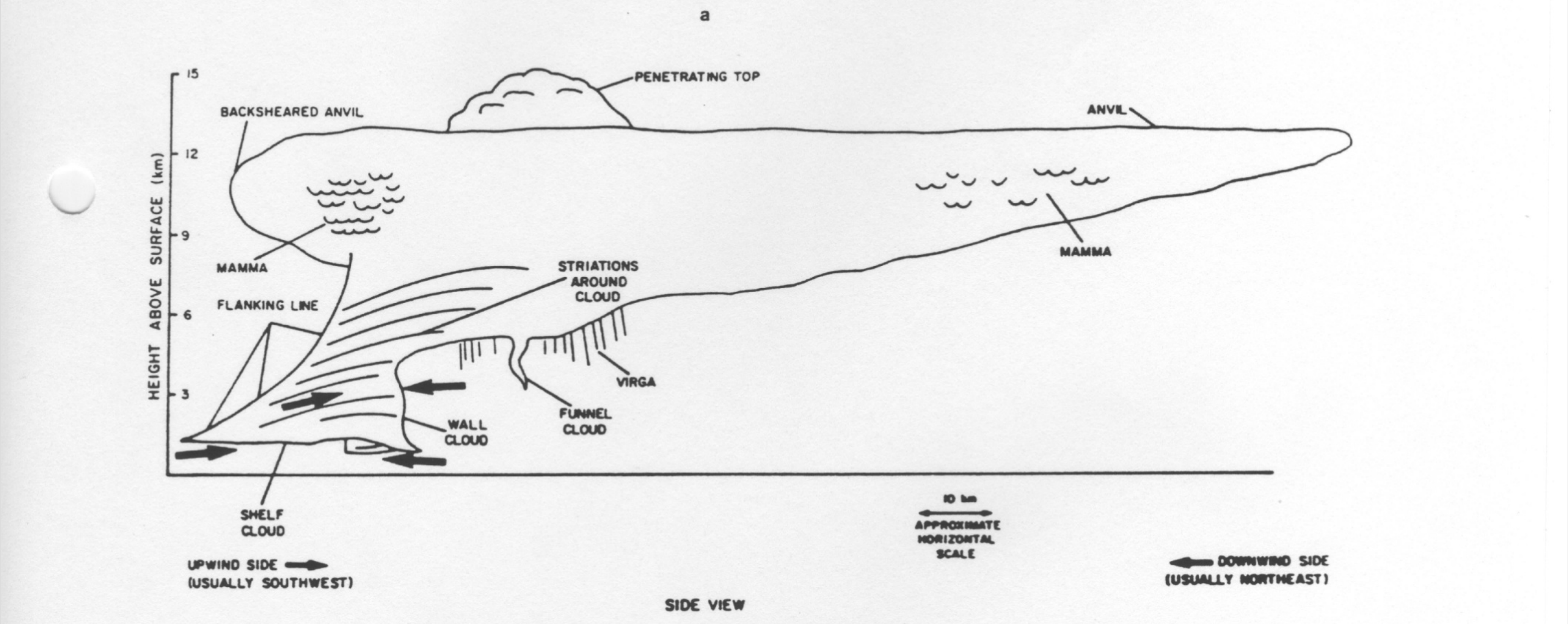




Skeletal "classic" supercell, looking WNW

photo © 1999 Jim Leonard

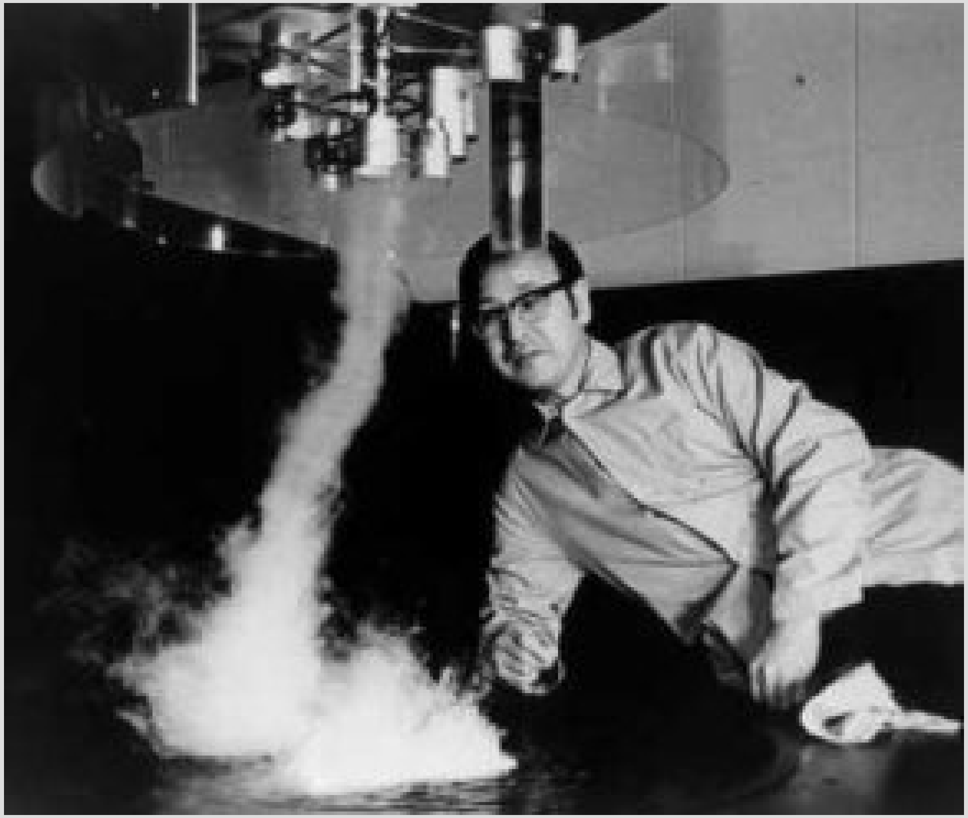
Low precipitation (LP) Supercell Form more along the dryline in western Great Plains



These require less shear because there is little associated precipitation to produce a cold pool.


Weather-Photos.Net
© 2013 Marko Korošec

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

Winds: 65-85 mph

Damage: Broken tree branches and signs.

EF1: Weak

Miami, FL

Winds: 86-110 mph

Damage: Small trees snapped and windows broken

EF2: Strong

Winds: 111-135 mph

Damage: Large trees uprooted, weak structures destroyed

EF3: Very Strong

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

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

EF4: Violent

Winds: 166-200 mph

Damage: Major devastation of sturdy structures.

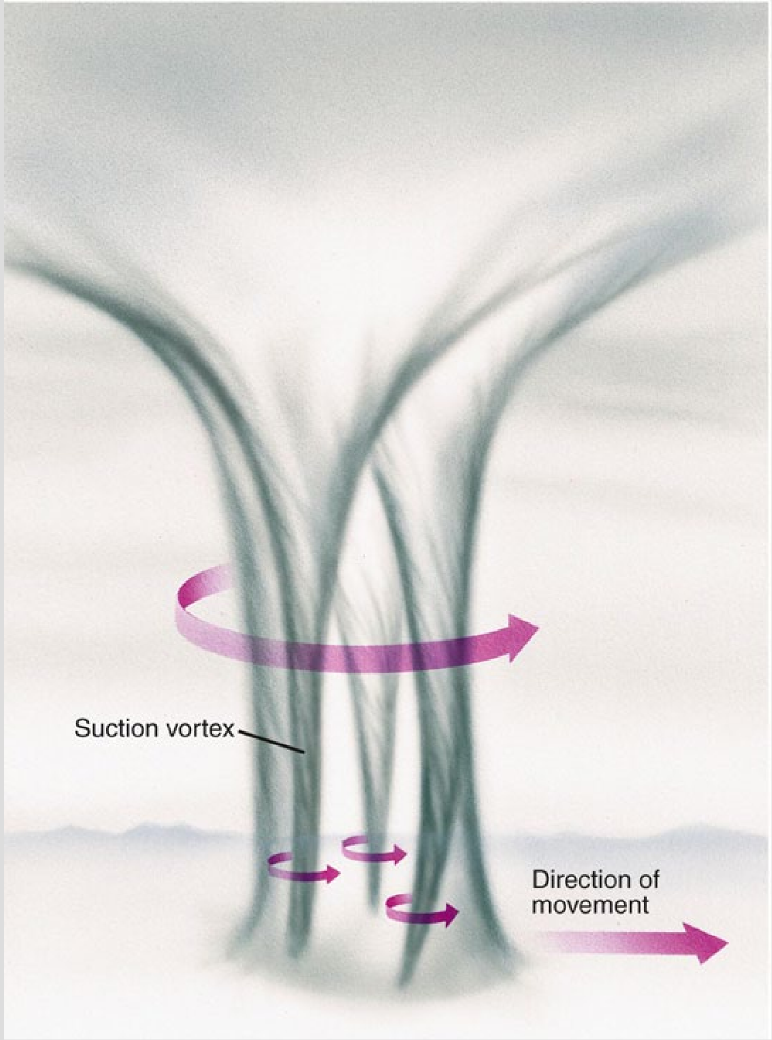
EF5: Catastrophic

Moore, OK
May 3, 1999

Winds: Over 200 mph

Damage: 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!

Vortex structure as function of the swirl ratio (v_T/w)

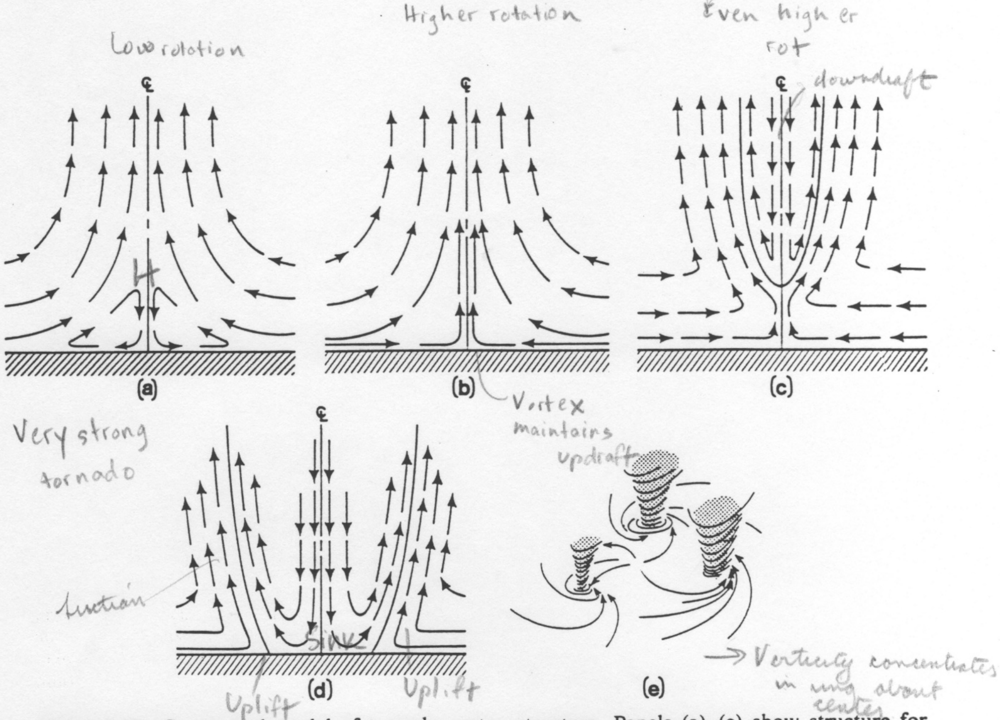
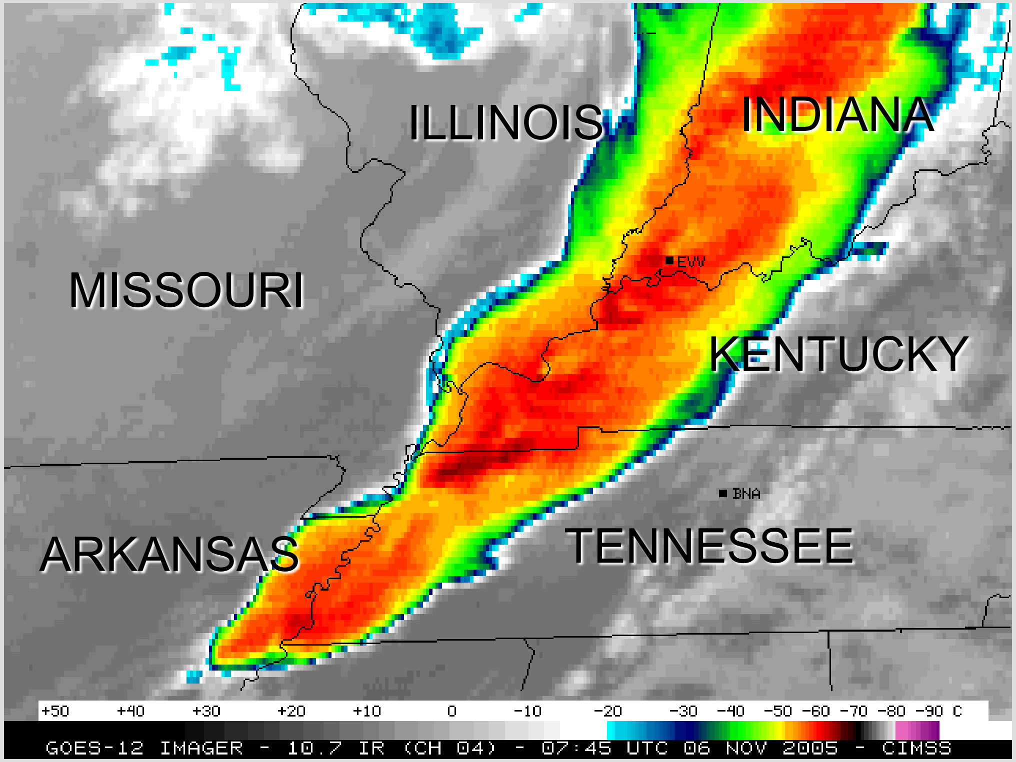


Figure 8.35 Conceptual model of tornado vortex structure. Panels (a)–(e) show structure for successively higher swirl ratio. (a) Weak swirl case: flow in boundary layer separates and passes around corner region. (b) One-cell vortex. (c) Vortex breakdown. (d) Two-cell vortex with downdraft impinging on ground. (e) Multiple vortices. The connected CL indicates the center line. (From Davies-Jones, 1986 and Lewellen, 1976.)

swirl ratio $\propto \frac{V_T}{w}$

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

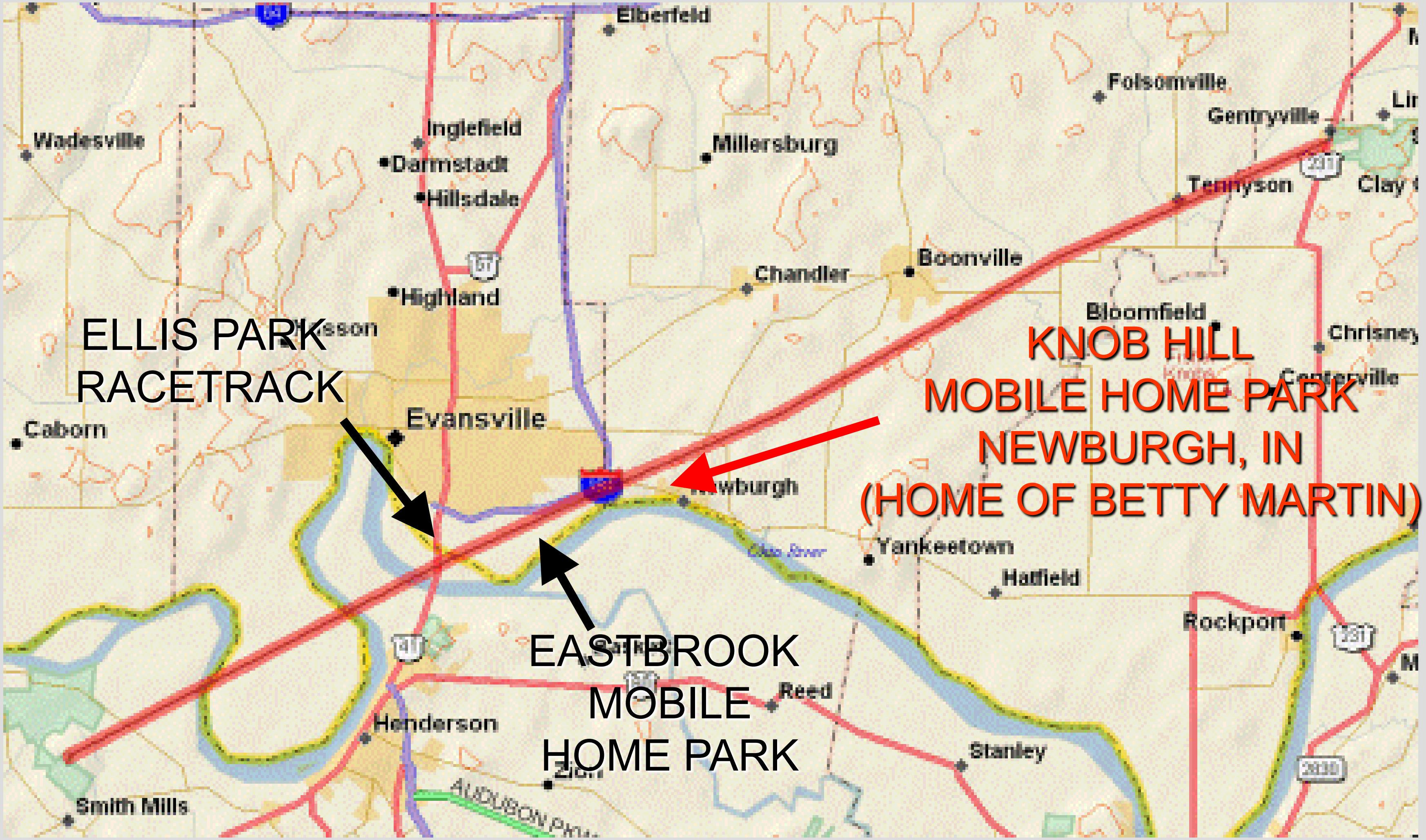
RADAR REFLECTIVITY

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

KNOB HILL MOBILE HOME PARK NEWBURGH, IN (HOME OF BETTY MARTIN)

EASTBROOK MOBILE HOME PARK

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.