

MET 4300

A large, dark, and dramatic supercell thunderstorm cloud formation dominates the sky. The clouds are thick and layered, with a bright, glowing area on the right side where the sun is partially obscured. The foreground shows a green field with a line of trees in the distance.

**Lecture 21
Supercell
Thunderstorms
(CH18)**

Supercell Thunderstorms

- The most intense thunderstorms
- The entire storm is a single entity, rather than a group of cells like an MCS or a frontal squall line.
- Produce most tornadoes, virtually all severe tornadoes, most large hail (as large as a grapefruit), and damaging straight-line winds.
- A single, long-lasting, rotating updraft typically 20-40 m/s, but up to 50 m/s.
- Four key ingredients to form
 - Conditionally unstable: humid & warm at the surface and dry & very cold aloft
 - Very moist air in the lower troposphere
 - Moderate to strong vertical wind shear through the depth of the unstable layer
 - A trigger mechanism -lifting
- Requires CAPE > 1500 (or so) and shear > 25 m/s

A Typical Sounding in the Supercell Environment

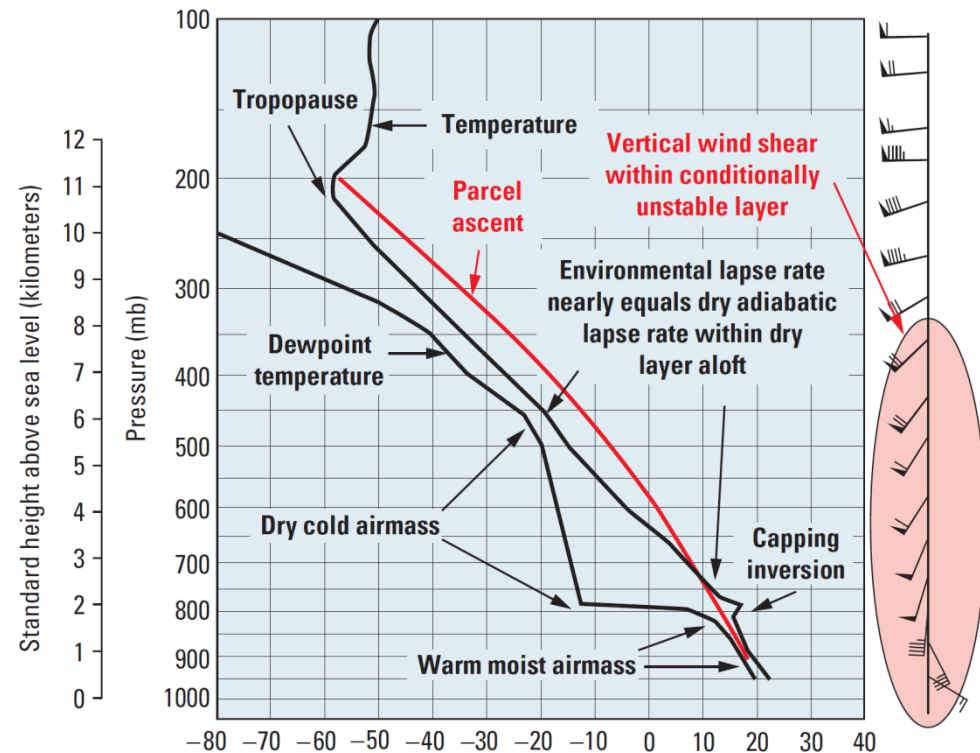
- Conditionally unstable with a warm and moist layer in the lower troposphere
- Aloft above the warm moist air is a dry/cold airmass.
- Over the Great Plains, the moist airmass is from the Gulf, while the dry airmass is from the mountains & high deserts to the west

- The two airmasses are often separated by a capping inversion:

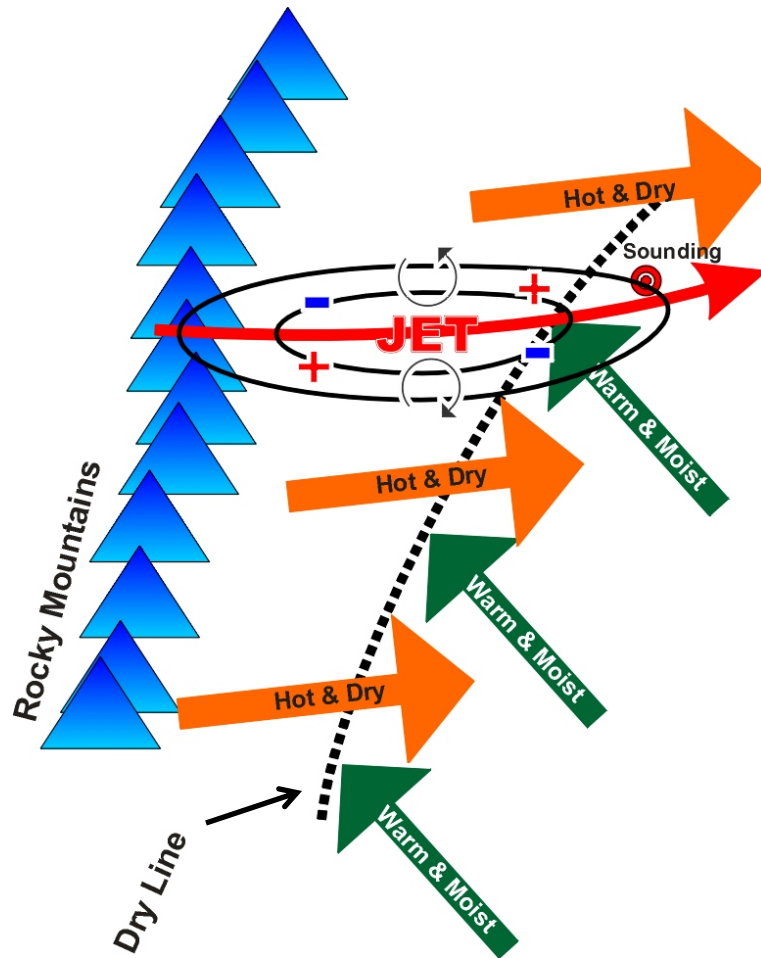
- The dry air aloft has descended as it moved eastward away from the Rockies
- It serves as a weak lid and keeps the first thunderstorm to form too early

- A strong vertical wind shear within the layer of max instability

- Winds increase rapidly with height
- A low-level jet from just above the ground to just above the capping inversion, transporting the warm moist air northward and providing the low-level shear that support storm rotation.
- A jetstream just below the tropopause.



Stability and Triggering

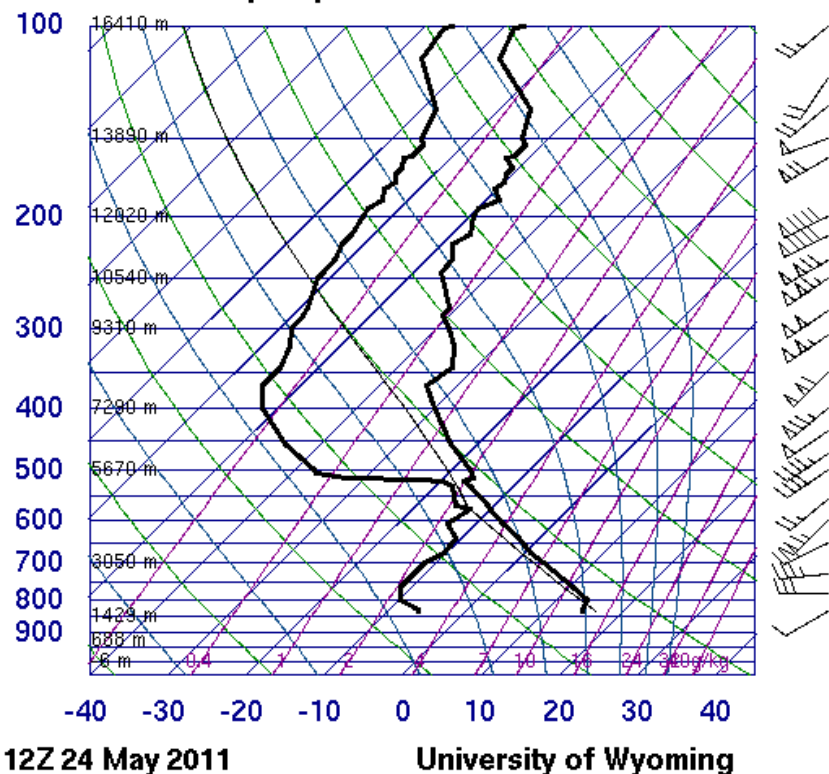


- Warm, moist air arrives from the Gulf of Mexico to the SE
- Hot, dry air arrives from the foothills of the Rockies and from the deserts
- Flows over the moist air
- Creating the Capping Inversion with both CAPE and CIN
- Called the “Elevated Mixed Layer” (EML)
- Upper level Jet Streaks promote rising motion in the right entrance and left exit regions

Elevated Mixed Layer (EML)

- **Mixed layer** is a zone having nearly constant potential temperature (and sometime specific humidity) with height. In such a layer the temperature falls at a rate of approximately $10\text{ }^{\circ}\text{C}/\text{km}$, provided it is free of clouds.
- Forms at surface in Southwest US, advected NE by mid-level flow
- Undercut by warm, moist flow from Gulf
- Dry/moist air divided by “dryline”
- To the east of the surface dryline, the moist layer is capped by the EML. To the west of the dryline, the mixed layer extends all the way to the ground and is not "elevated".
- Responsible for capping inversion underneath the EML. The inversion allows large values of CAPE to build up before convection initiates
- If EML is too strong and/or no trigger mechanism present, storms may not develop despite high instability

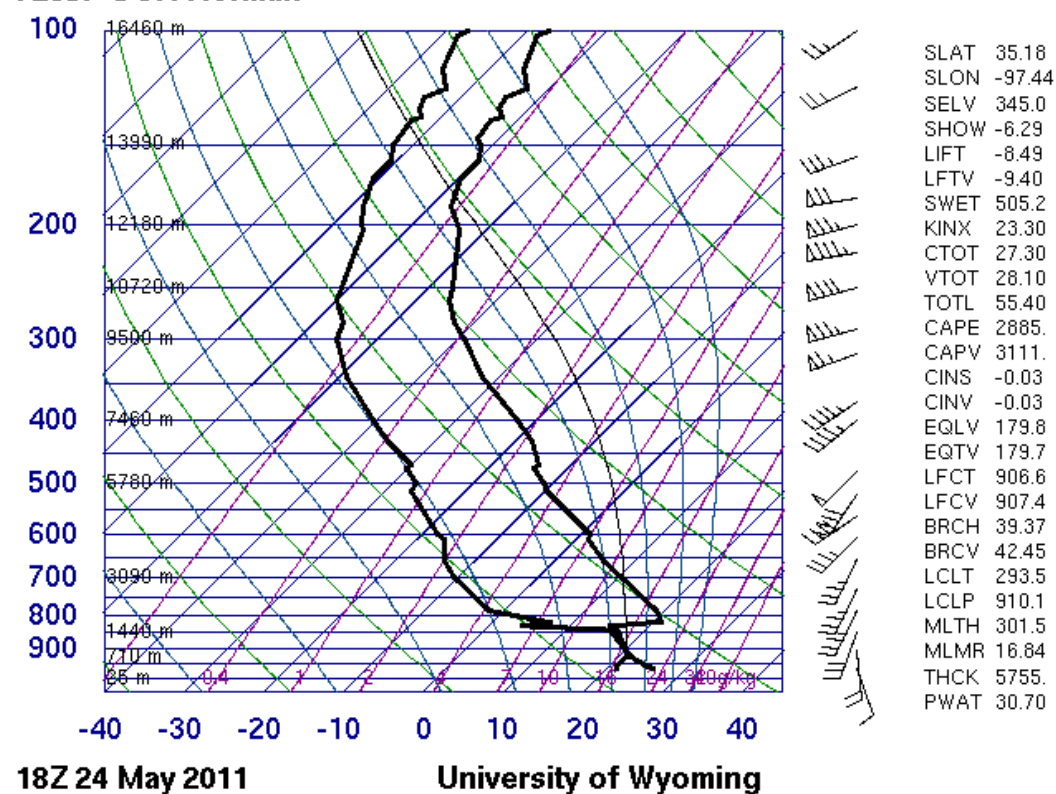
72365 ABQ Albuquerque



Albuquerque 12 Z

- Mixed layer up to 550 mb
- Well-mixed =
 - Temperature follows dry adiabats (green)
 - Dew point follows constant sat. mixing ratio (purple)

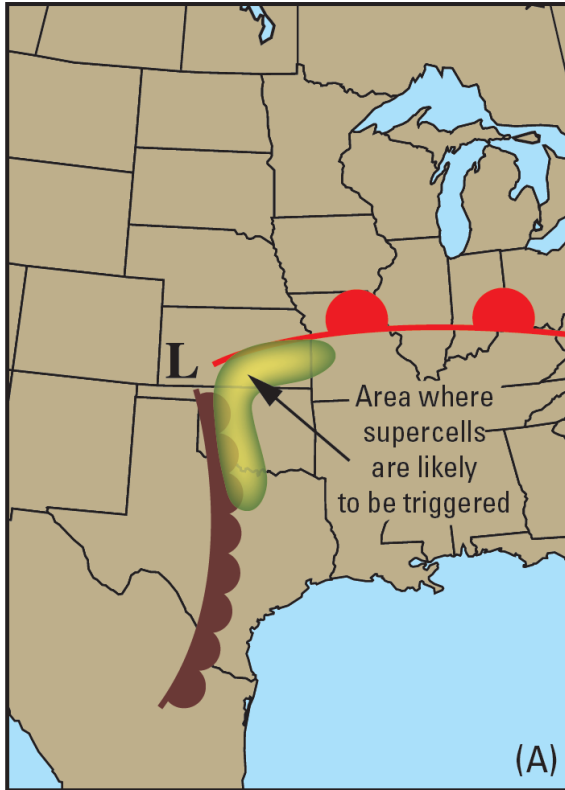
72357 OUN Norman



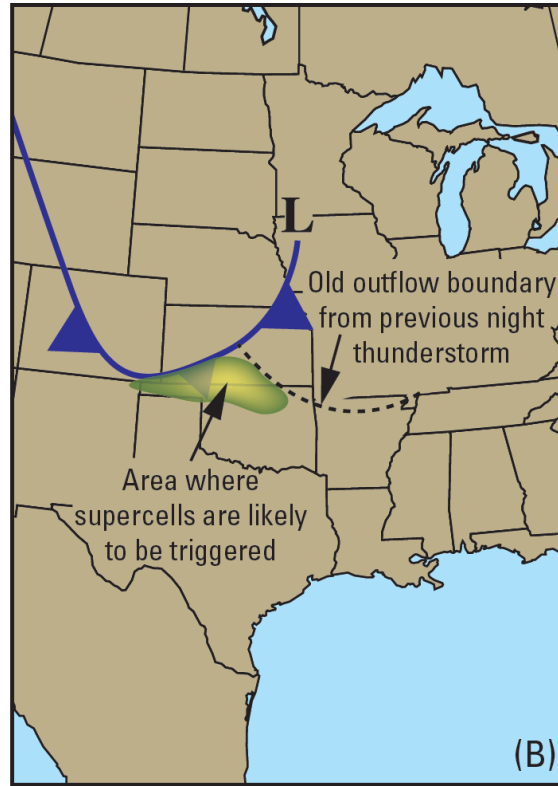
Norman 18 Z

- Two mixed layers on this sounding
 - Boundary layer: surface-850 mb
 - EML: 850 mb – 500 mb
- CAPE = 2,885 J/kg
- Veering wind profile

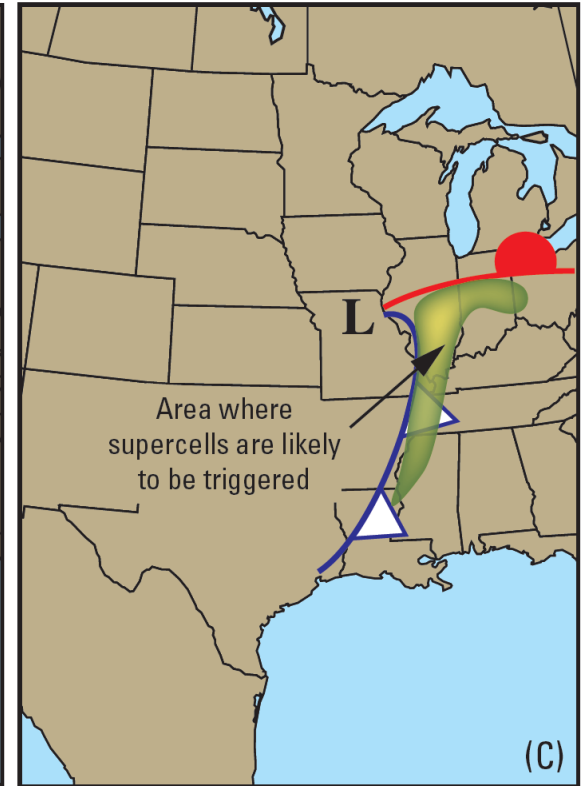
Supercell Conditions (Weather Patterns)



Warm moist air is east of a **dry line** and south of a **warm front**

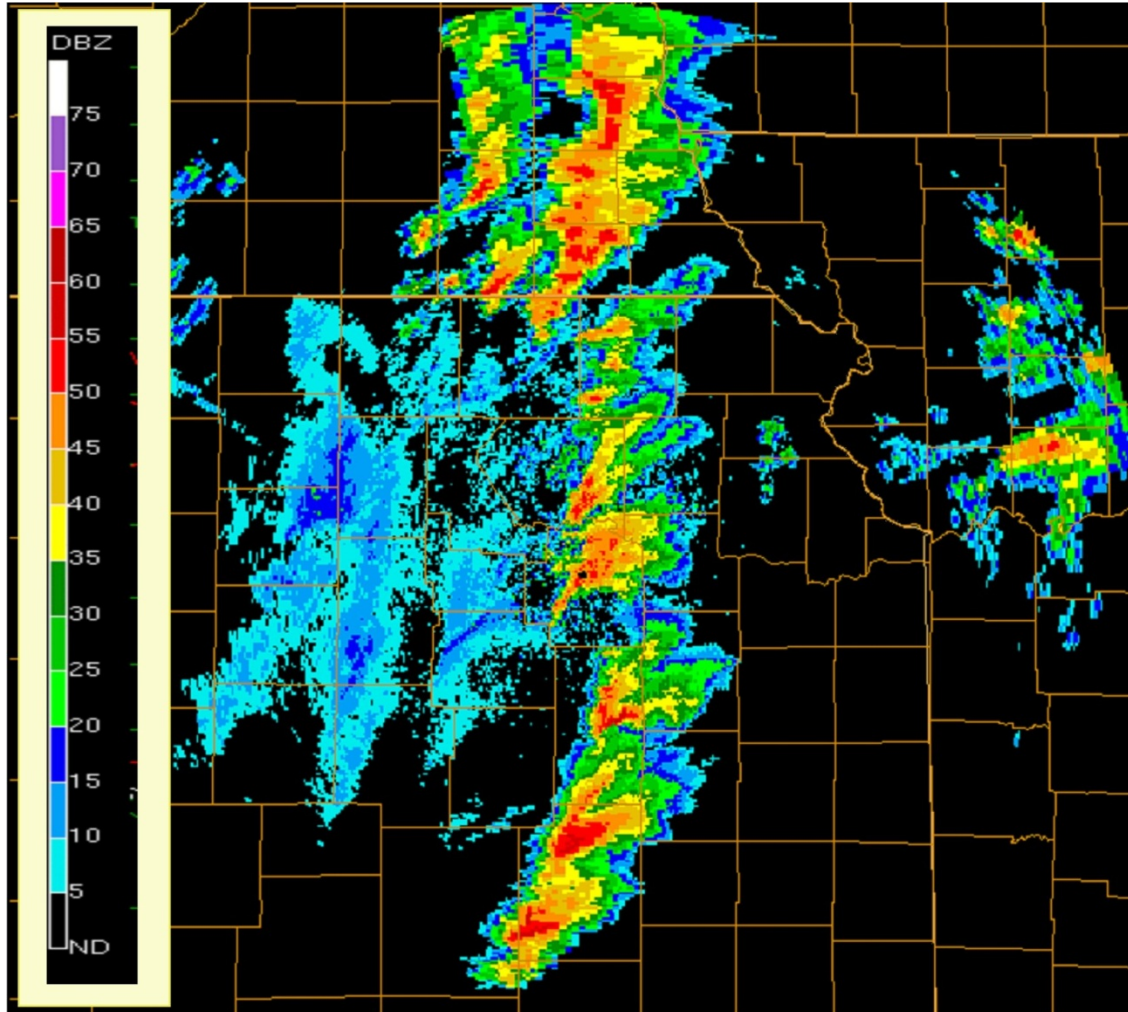


An **old outflow boundary** & a **cold front** trigger supercells



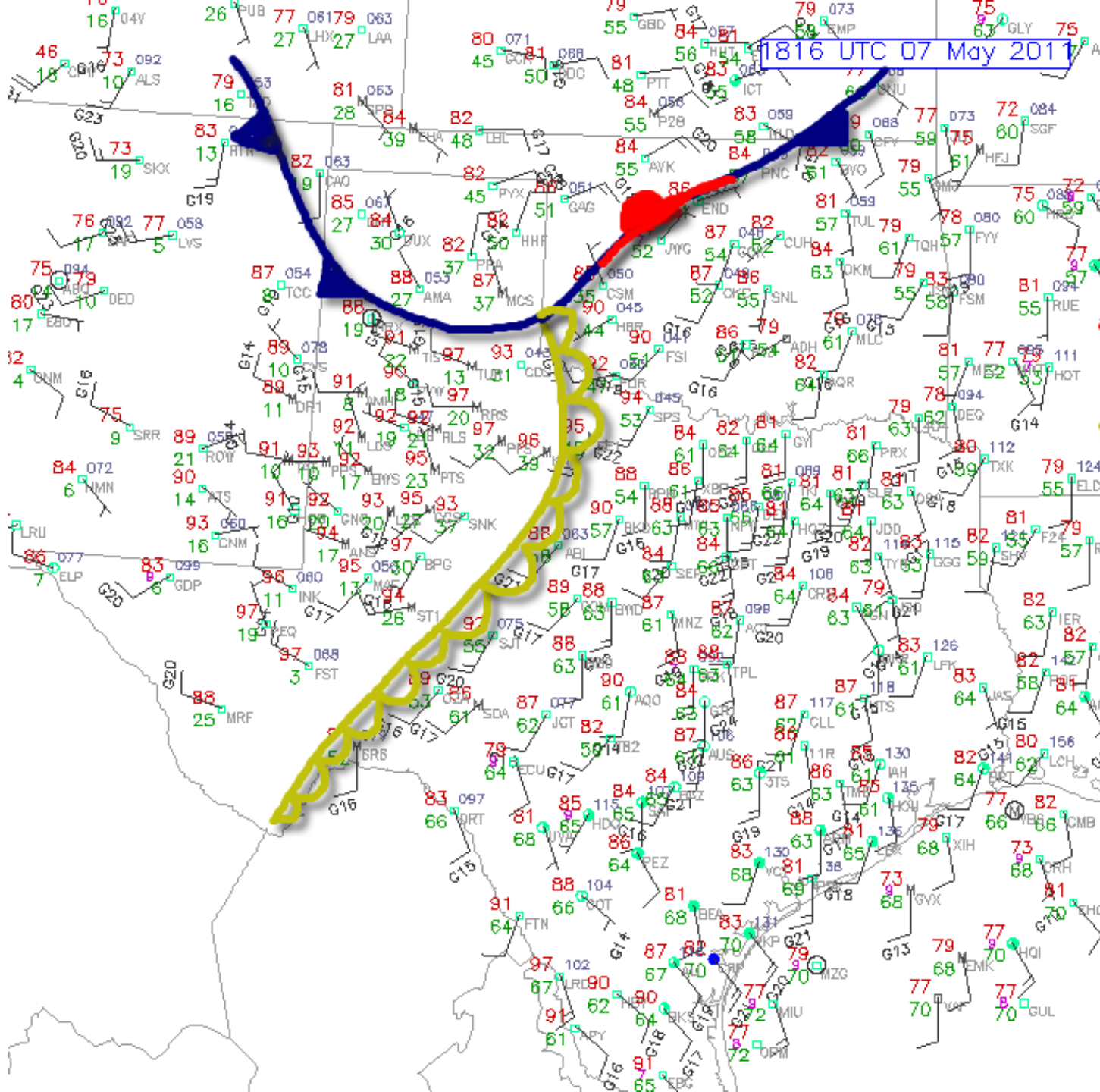
Lifting is provided by an **upper-level front** and a **warm front**

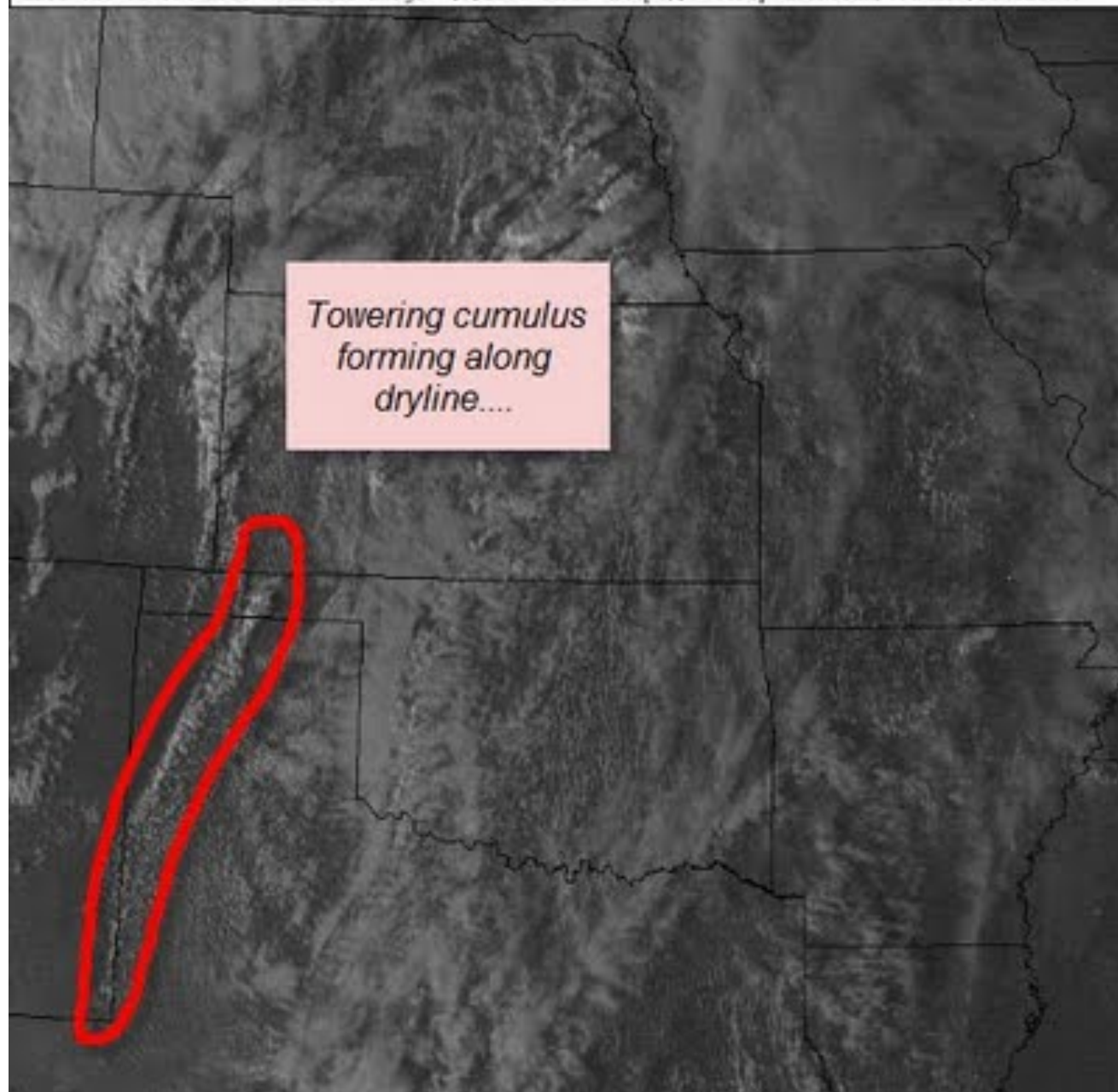
Radar image of a line of supercells



- First supercell tends to develop at the intersection of boundaries.
- Then new cells are often triggered by the gust front outflow, creating a line of supercells.

1816 UTC 07 May 2011





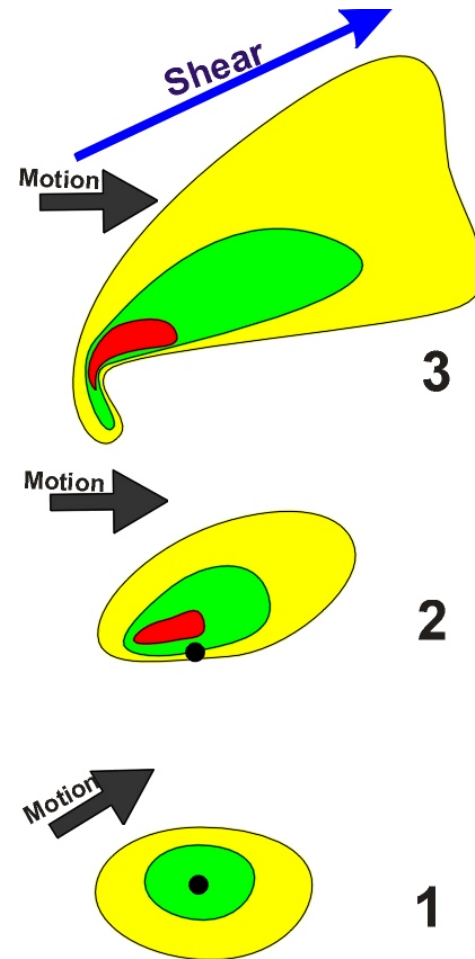
*Towering cumulus
forming along
dryline....*



(b)

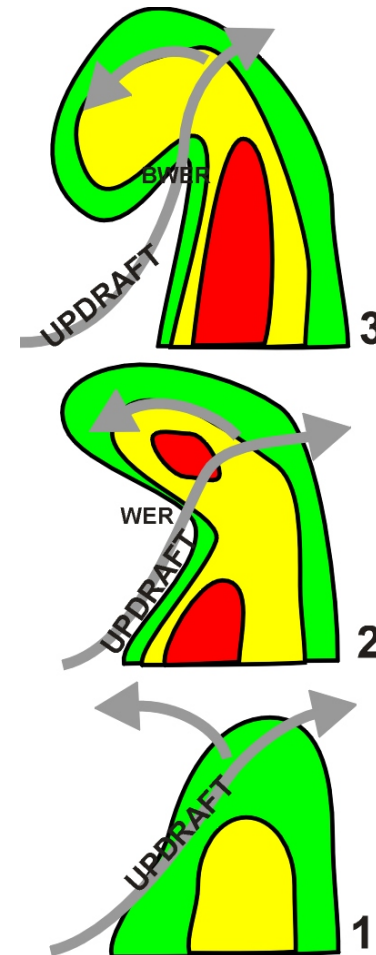
Supercell Evolution in Plan View

- Initially more or less round
- Moves with surrounding wind
- Becomes elongated parallel with shear.
- Hook-like appendage on SW flank
- Wraps around the “Echo-free vault or Bounded Weak Echo Region (BWER)”
- Moves to the right of the shear

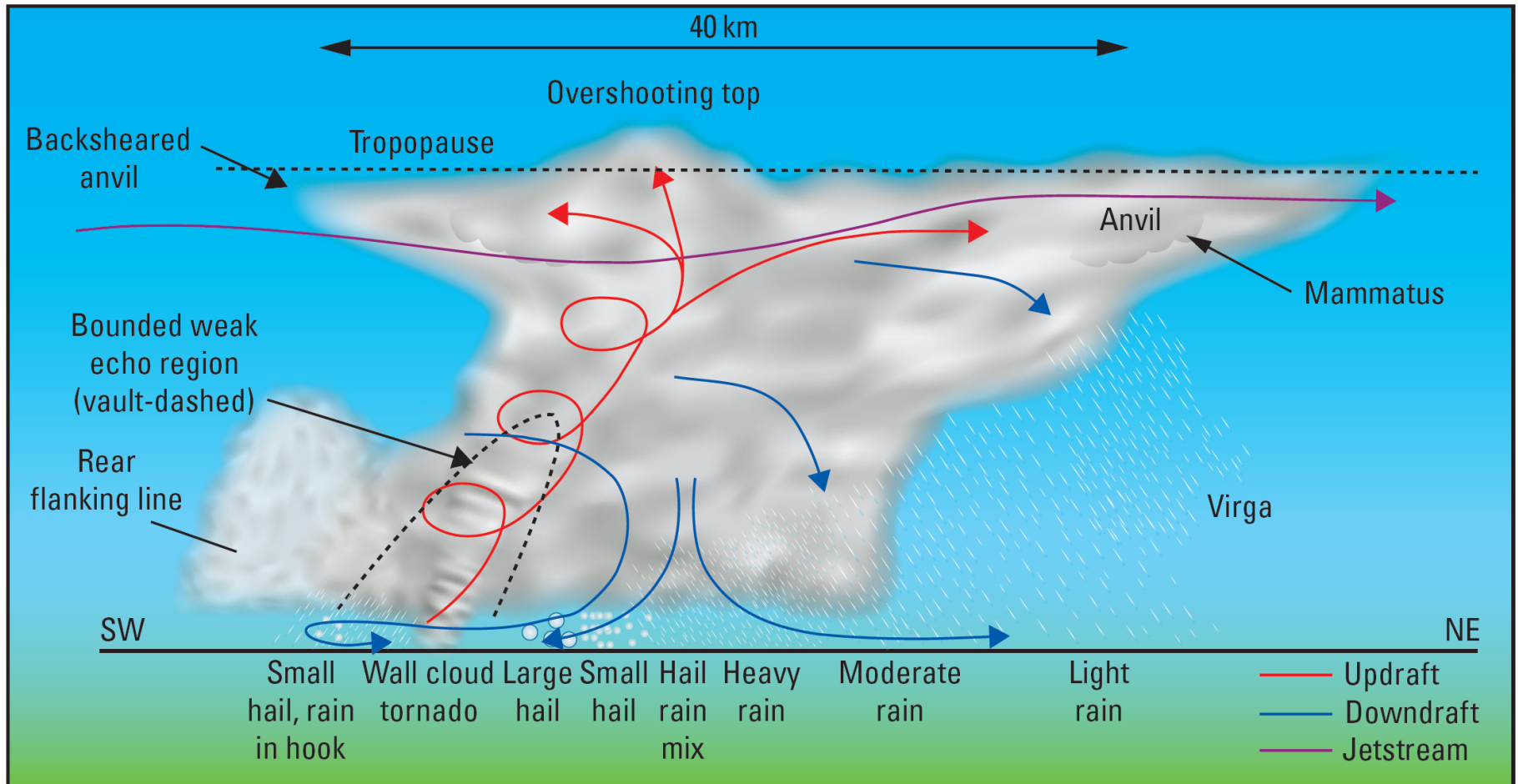


Supercell Evolution in Vertical View

- A single, long-lasting, rotating cell.
- Starts as a multicell storm
- Development
 - Single vertically aligned cell dominates
 - After an hour, tight gradient and low reflectivity on SW flank
 - Middle level reflectivity overhangs updraft (Weak Echo Region)
 - Matures in 90 minutes
 - Updraft rises in “Echo-free vault or Bounded Weak Echo Region.
 - Precipitation (Hail) carried across storm to other side.
 - Thus it never loads the updraft



Supercell in Vertical Cross Section



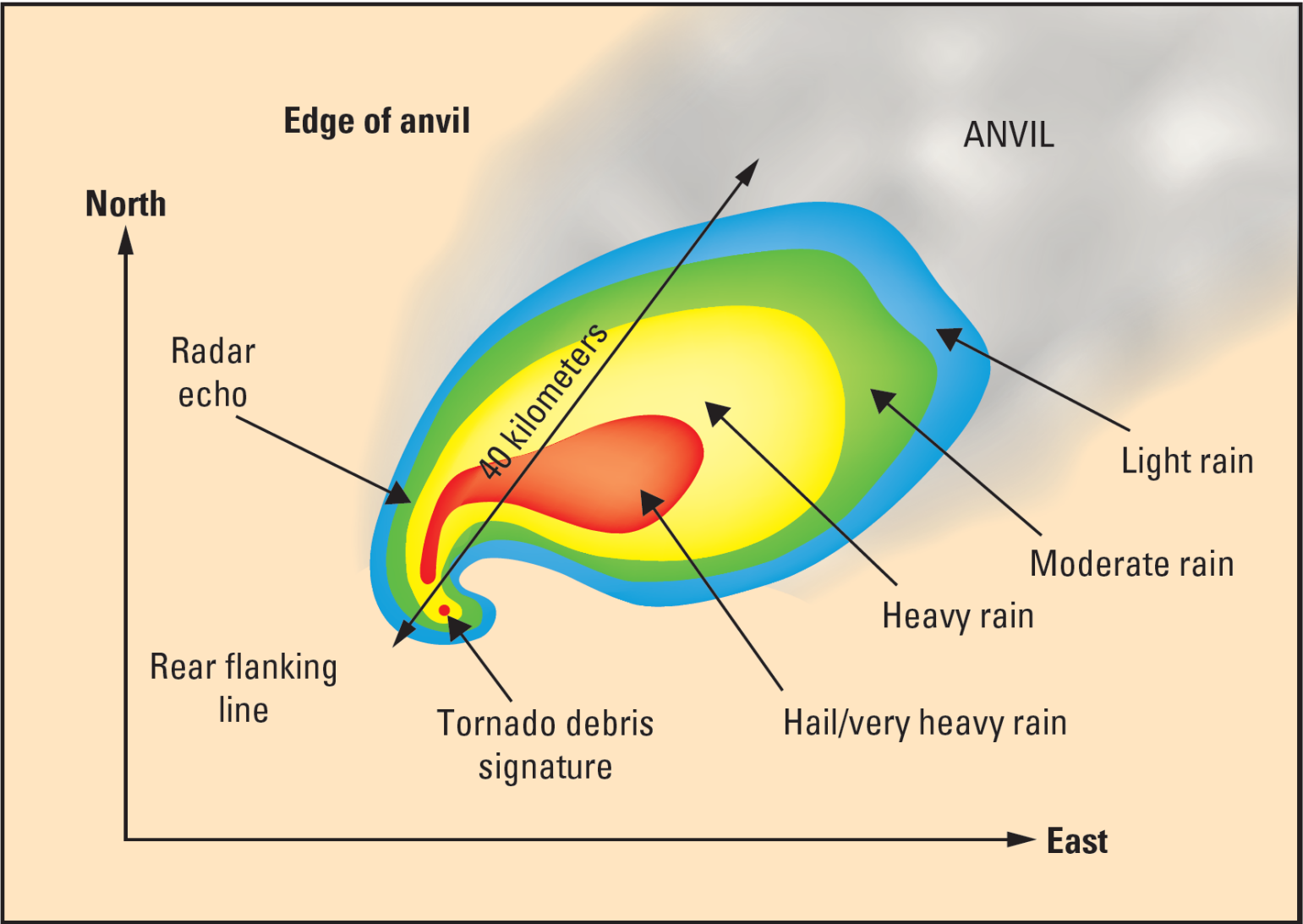
Features in vertical cross section of a supercell

- Typical size of a supercell: 40 km across
- **Mesocyclone**: rotating updraft, SW side, 5-10km in diameter.
- **Overshooting top**: updraft rises to the tropopause & penetrates into the stratosphere, before descending back.
- **Rain-free base**: is formed due to strong SW winds in the middle and upper level (strong wind shear), so precipitation are carried northeastward, never fall in the core of updraft, leaving a rain-free base.
- **Echo Free Vault or Bounded Weak Echo Region (BWER)**: cloud particles are so small above the rain free base so that they produce only weak or no radar echoes.
- **Wall cloud**: a region of low cloud hanging from the rain-free cloud base. It can take many different sizes and shapes: *ragged, shallow, or very large, often visibly rotating*. The lowering of cloud base develops as low-level moist air originating within the forward flank precipitation region is ingested into the updraft.
- **Tornadoes**: often emerge just below the wall cloud. They occur in the vicinity of the intense updraft, outside of the heavy precipitation region.
- **Anvil**: due to strong jetstream; Can extend hundreds of kilometers downstream (NE); can produce **virga**, & **mamatus clouds**.
- **Flanking line**: A line of convective cells forms to the SW of a supercell, aligning with the **rear flank gust front**.

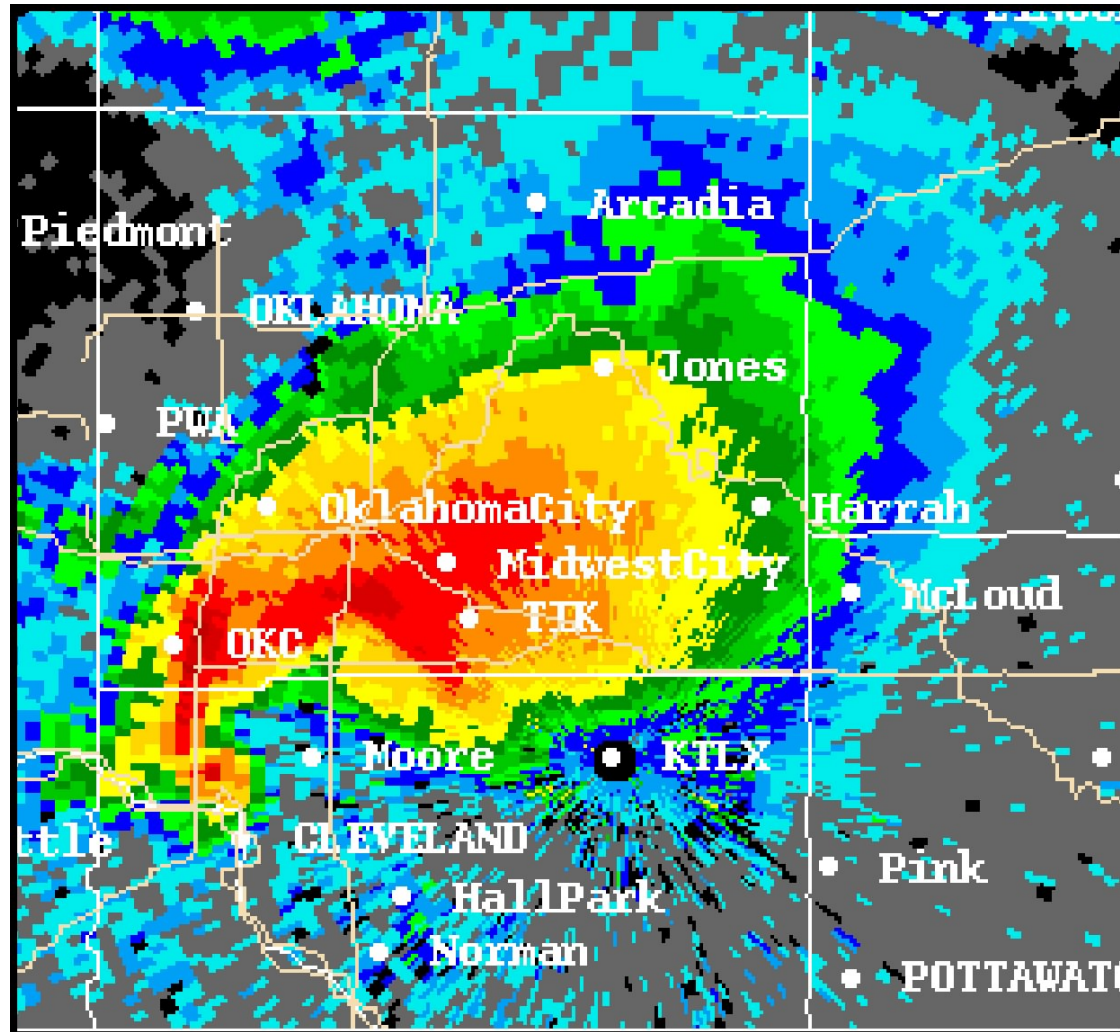
A Wall Cloud



Plan View (horizontal cross section) of a Classic Supercell



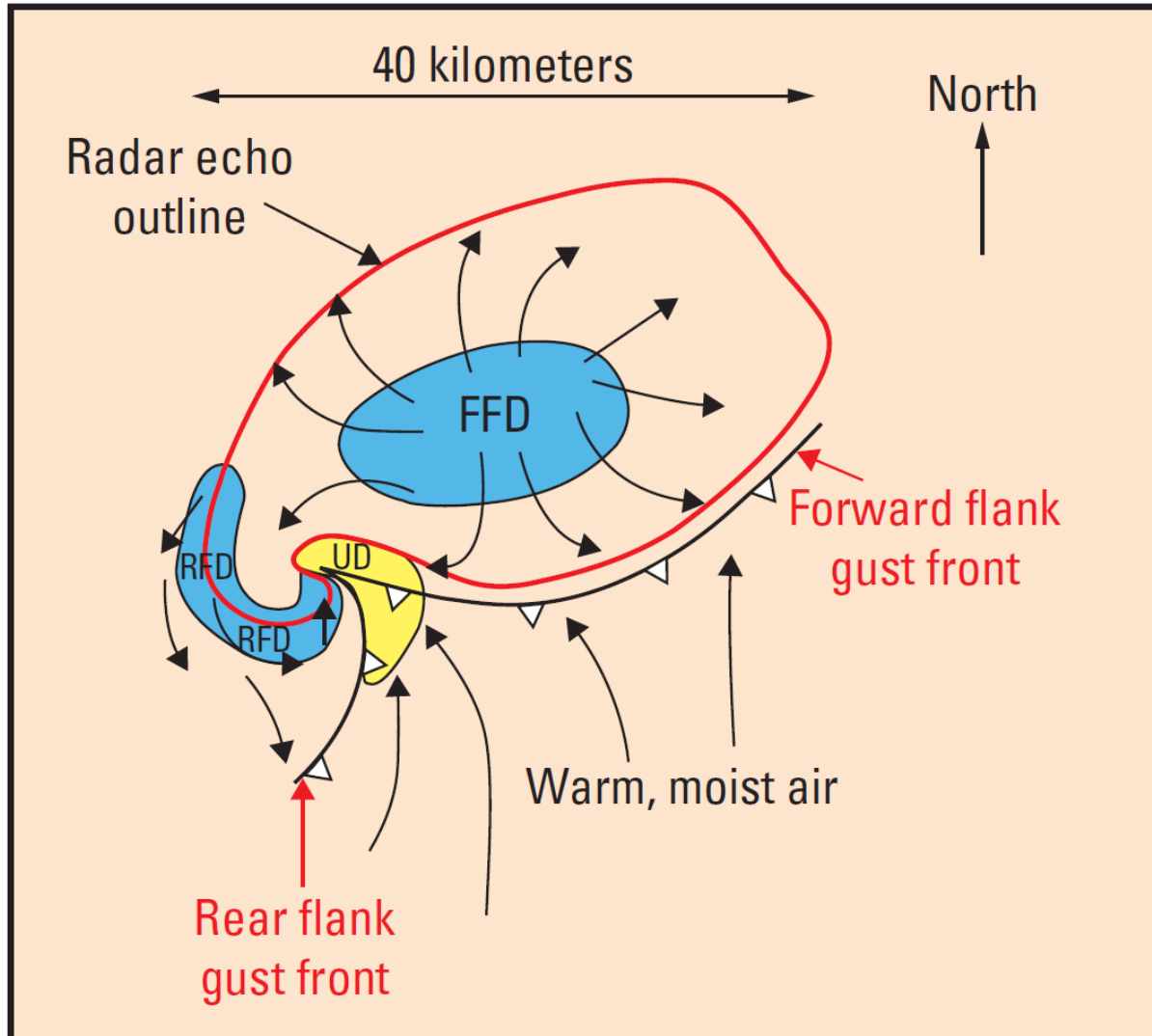
Radar Image of the May 3, 1999 Oklahoma City supercell thunderstorm



Features in the horizontal cross section

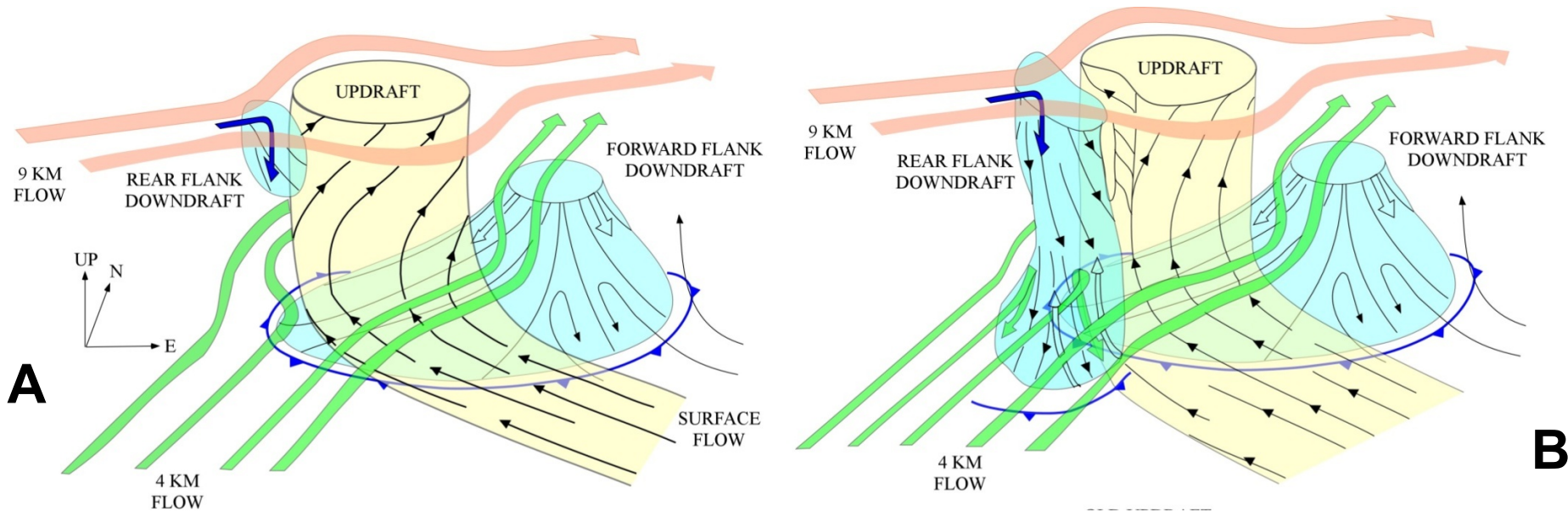
- **Intense rainfall:** located to N, NE, or E of the updraft region
- **Updraft (or BWER):** within the rain-free area adjacent to the hook echo on the SW side of the storm.
- **Hail:** falls on the perimeter of the updraft, adjacent to the rain-free base. Largest hail closest to the rain-free base.
- **Hook echo:** results from the precipitation swept around the SW side by the mesocyclone circulation within the storm.
- **Rear-flank downdraft:** induced by precipitation in the rear flank area.
- **Tornadoe signature:** the circular radar echo near the end of the hook echo, caused by the debris hurled skyward by a tornado.
- **Precipitation types to the NE:** larger hail, smaller hail, hail/rain mix, heavy rain, moderate rain, and then light rain
- **Supercell movement:** Typically to the right of the mid-troposphere winds, which are generally southwesterly.
- As a supercell moves over a town, people would first experience the conditions on the NE side (**forward flank**), then progressively conditions toward the SW side (**rear flank**).

A Slice through a super cell parallel to Earth's surface showing low-level air flow patterns



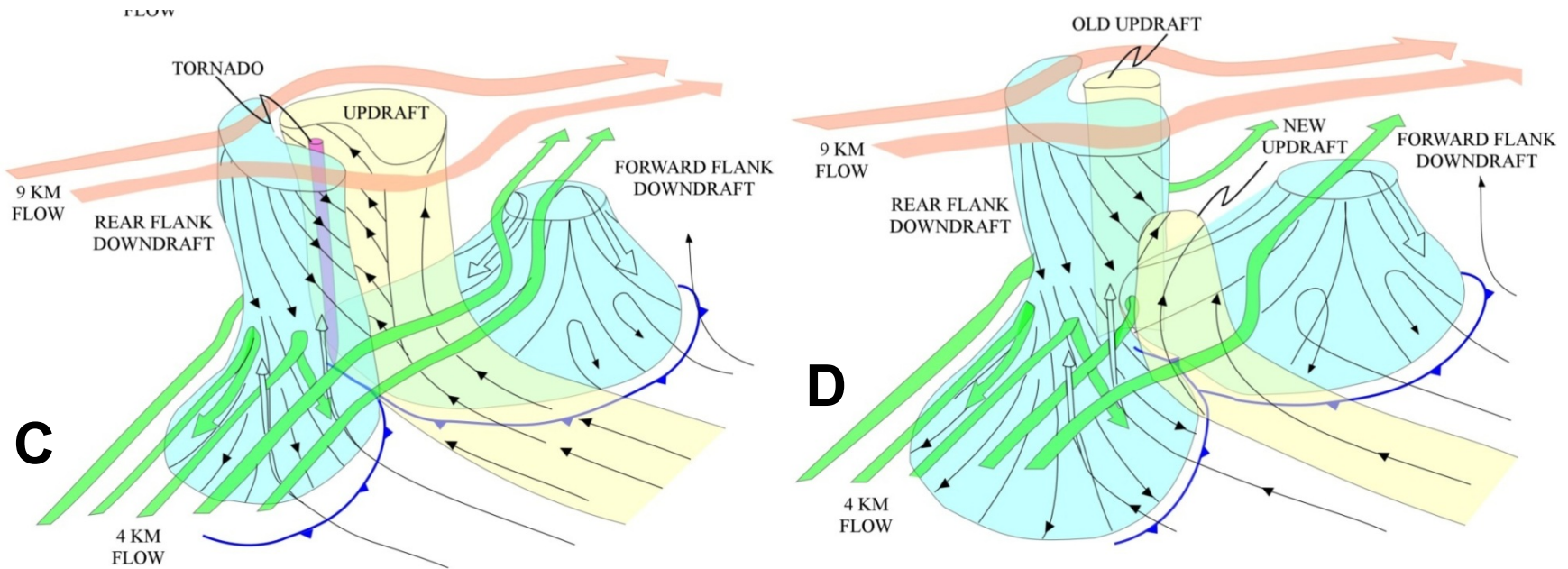
- FFD: forward flank downdraft
- RFD: rear flank downdraft
- UD: updraft

3D Supercell Evolution



- **Panel A (initial formation stage):** different level inflows approach the updraft core from all directions. Precipitation begins to N, NE and E sides, as particles are carried downwind by mid- & upper-level winds. **FFD** and **forward flank gust front** form at this stage.
- **Panel B (full formation stage with both FFD & RFD):** precipitation particles on the rear flank mix with the dry air within the mid & upper-level inflows and evaporate. This air cools & descends to the surface creating **RFD (rear flank downdraft)**.

3D Supercell Evolution



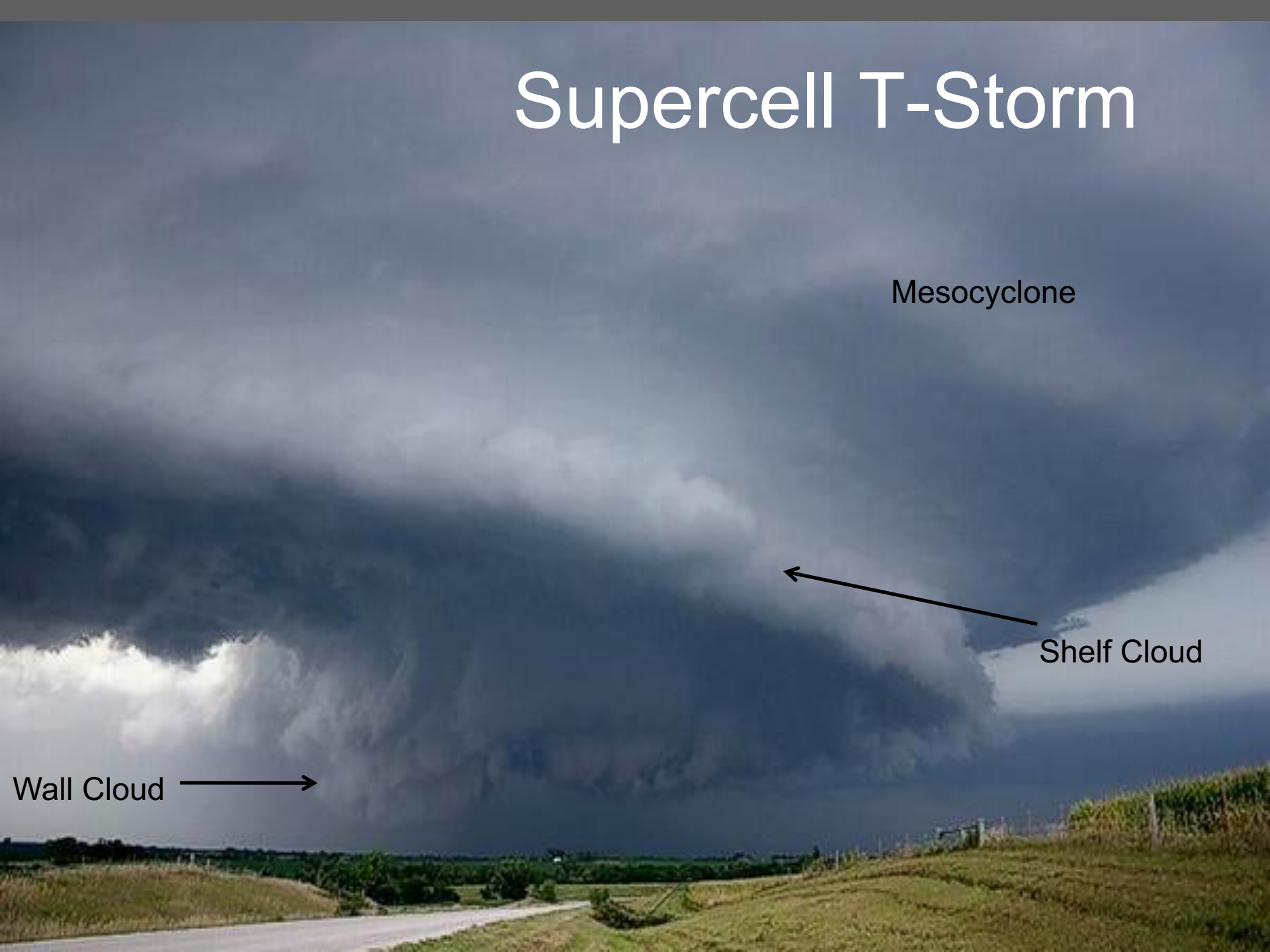
- **Panel C (mature stage with a strong rotating updraft & tornado located at the coupling of the updraft & RFD):** Precipitation in the RFD wraps around the updraft due to circulation of mesocyclone, creating the hook radar echo. Rear flank gust front triggers new cells, creating a flanking line of convection.
- **Panel D (decaying stage):** the rear flank downdrafts wraps around the updraft, cutting off its supply of warm and moist air.

Supercell T-Storm

Mesocyclone

Shelf Cloud

Wall Cloud

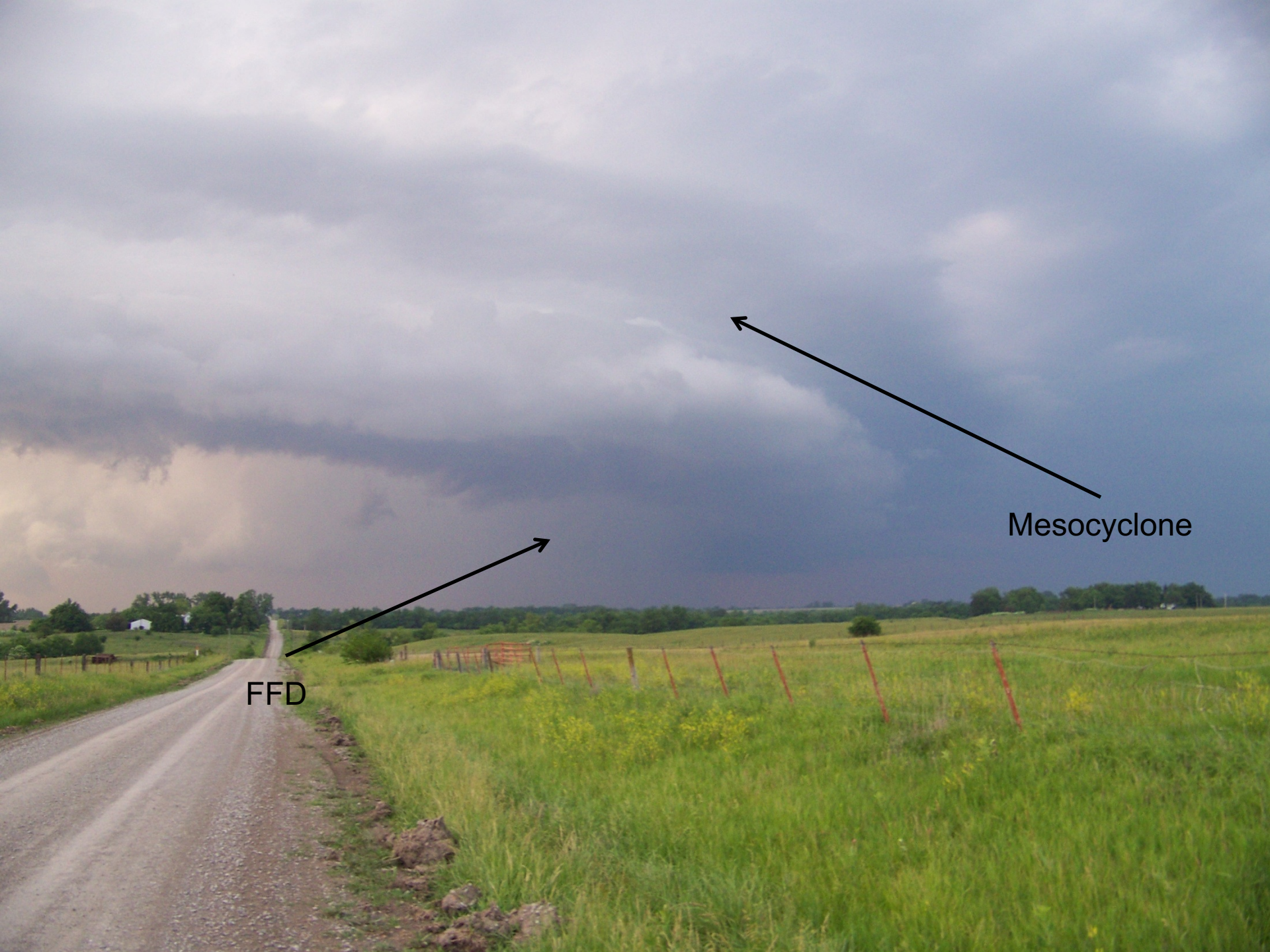


Another Supercell T Storm



Mesovortex Wall Cloud





FFD

Mesocyclone



Tornado



Beaver Tail (inflow band)

Summary

- Supercells are long lasting thunderstorms that depend upon instability, shear and dry middle levels.
- Sloping updraft is able to unload hydrometeors
- Lower and middle level inflows circle around each other in the mesocyclone to produce front- and rear-flank downdrafts on either side of the bounded weak echo region
- Merging outflow boundaries localize the updraft
- Move SW to NE, generally in the warm sectors of frontal cyclones under jet streaks
- Vorticity tilting and stretching in the mesocyclone often produces tornadoes