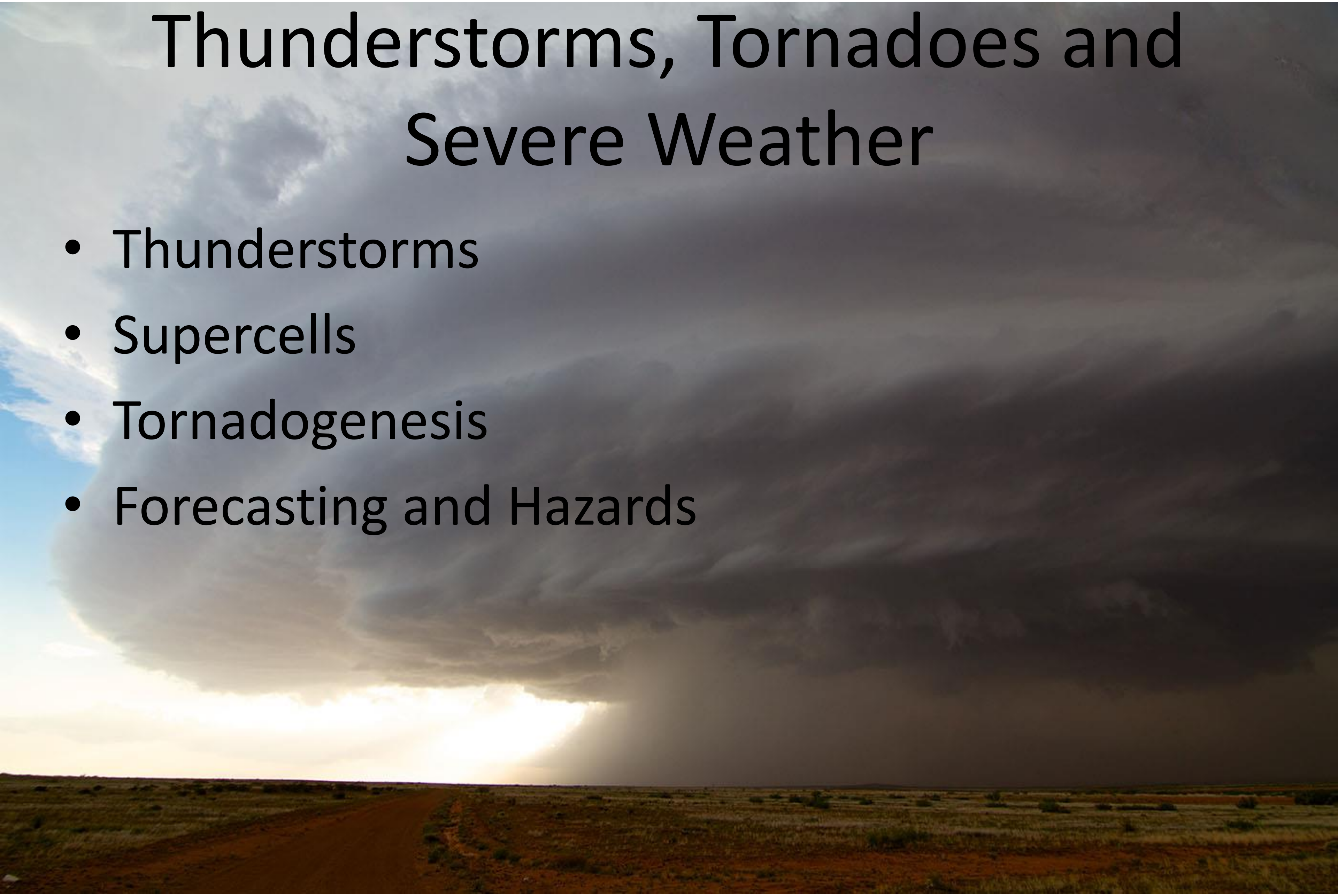
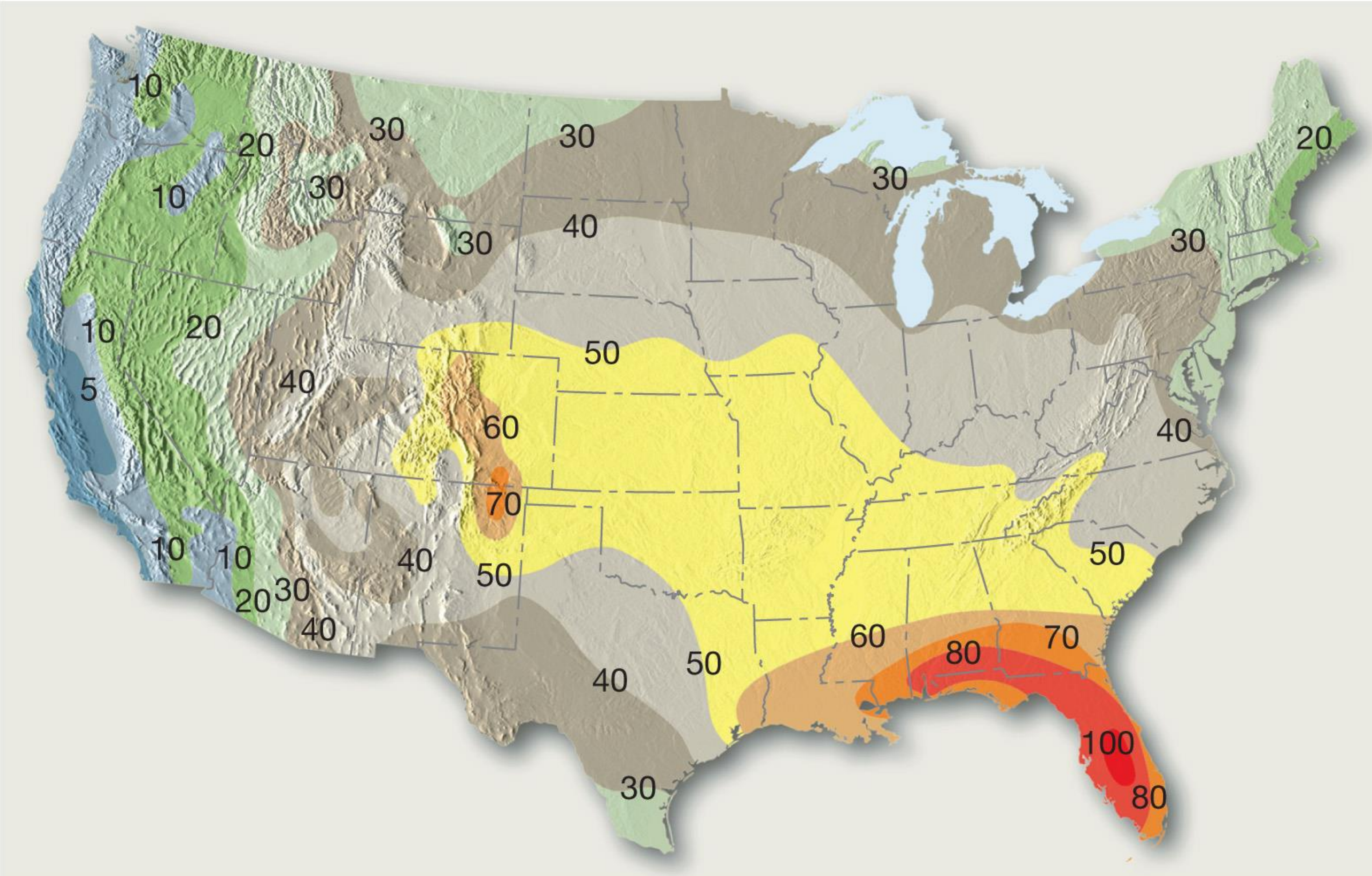
Thunderstorms, Tornadoes and Severe Weather



- Thunderstorms
- Supercells
- Tornadogenesis
- Forecasting and Hazards



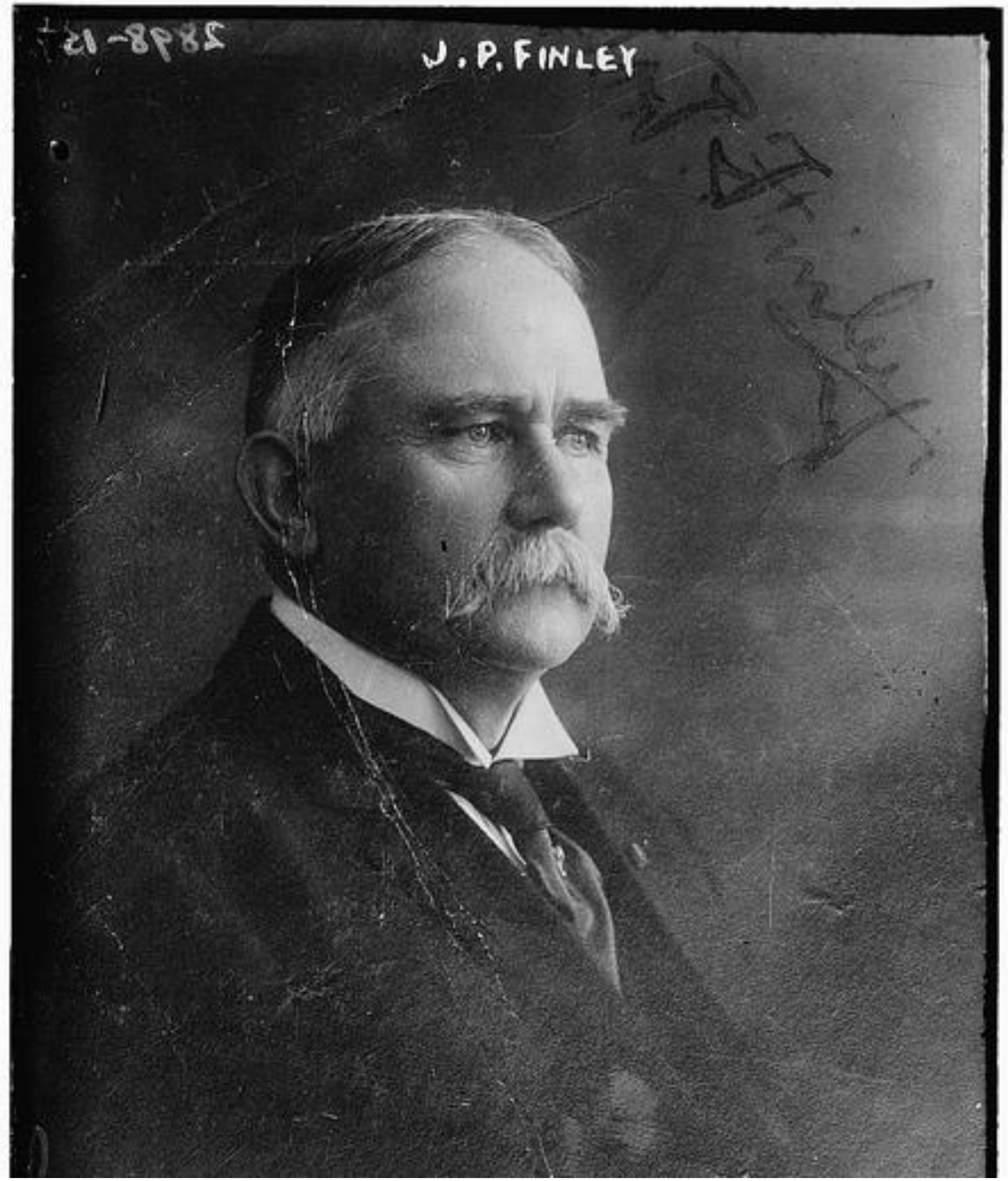
(b) **Average number of days per year with thunderstorms.**

John Park Finley

"As an area of low barometer advances to the Lower Missouri Valley, warm and cold currents set in towards it from the north and south, respectively. Warm and moist regions emanate from the Gulf and the cold and comparatively dry air from regions of the British Possessions [Canada]. The marked contrasts of temperature and moisture, invariably foretell an atmospheric disturbance of unusual violence, for which this region is peculiarly fitted...."

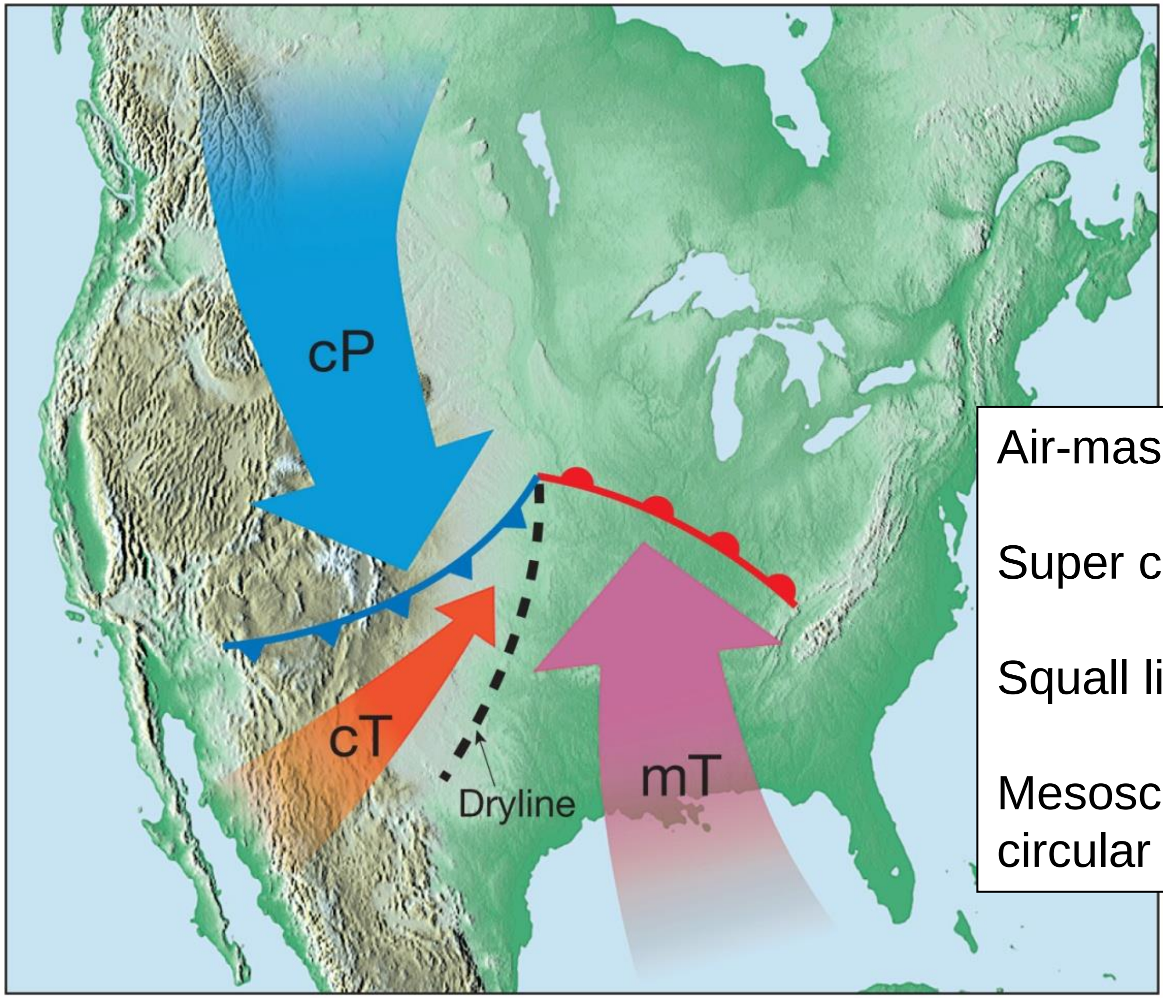
published as a Signal Service *Professional Paper* in 1881

In 1882 Finley established a network of "storm reporters" to gather severe storm information for the daily weather map makers in Washington.



Source: Bain News Service,, publisher

Cyclone: circulation around any low pressure center (not size dependent)
mid-latitude (1000 mile), hurricane (375 mile), tornado (0.16 mile)



Air-mass Thunderstorms

Super cells (2k-3k/yr)

Squall lines: elongated cluster of cells

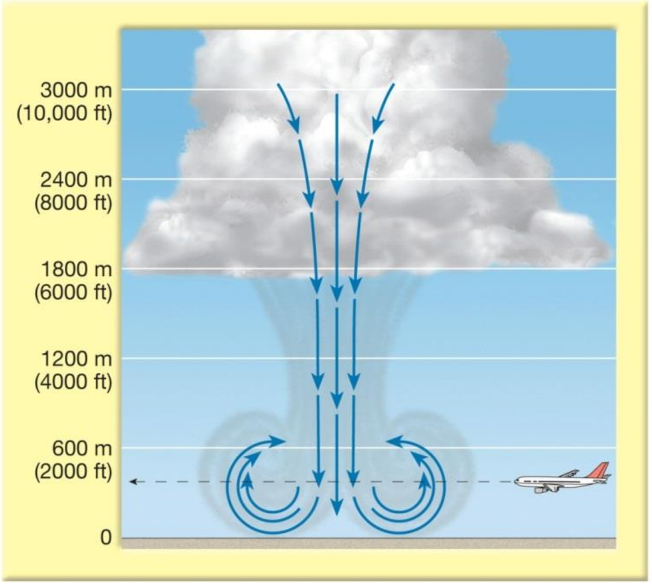
Mesoscale Convective Complex:
circular cluster of cells

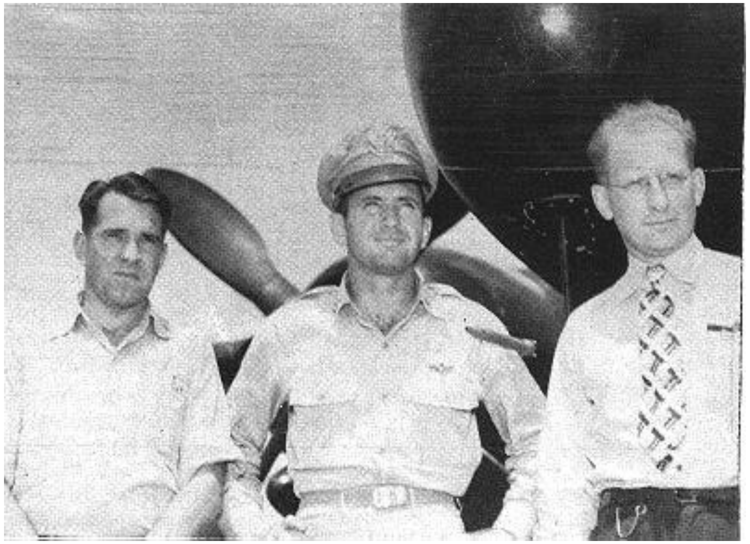
US: 100,000 thunderstorms annually, 10% severe, 1300 tornados

The Thunderstorm Project

The Weather Bureau during 1945 initiated a project for study of the development and structure of individual thunderstorm cells.

“Observations and measurements in thunderstorms will be obtained over an area of about sixty square miles in the Orlando locality by means of airplane and glider flights, three radiosonde and several radar stations, and approximately fifty surface recording stations.”





* Ferguson Hall (L) Lt. Col. Lewis Meng (C) Dr. Horace Byers (R)

Source: http://www.history.noaa.gov/stories_tales/thunder0.html

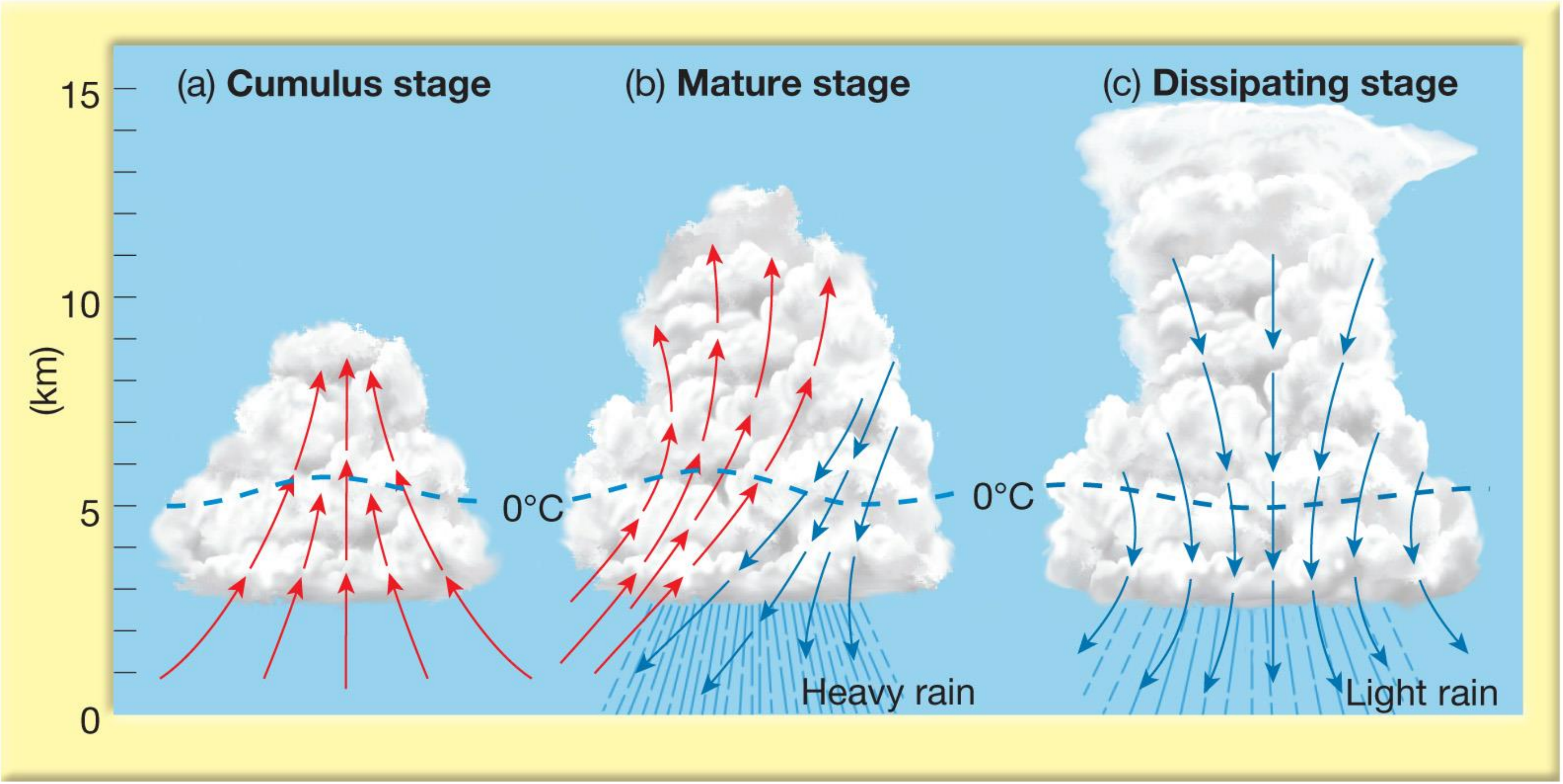
Ingredients for thunderstorm development

- In 1987 Charles (Chuck) Doswell simplified the list of ingredients necessary for thunderstorm production
- Instability
- Moisture
- Lift
- Shear (added later, super cells (squall lines, convective complexes))

Ingredients for Thunderstorm Development

- Instability
  - Warm air trapped below cooler air aloft: density differentials
- Moisture
  - At the macroscopic scale it comes from the Gulf of Mexico
  - At smaller scales it comes from the grasses, corns and wheat! Evapotranspiration.
- Lift
  - Mechanical
    - Orographic (of considerable importance in eastern Colorado)
    - Convergence
    - Frontal Wedging
  - Buoyant
    - Latent heat!

Stages of Thunderstorm Development



Thunderstorm stages of development

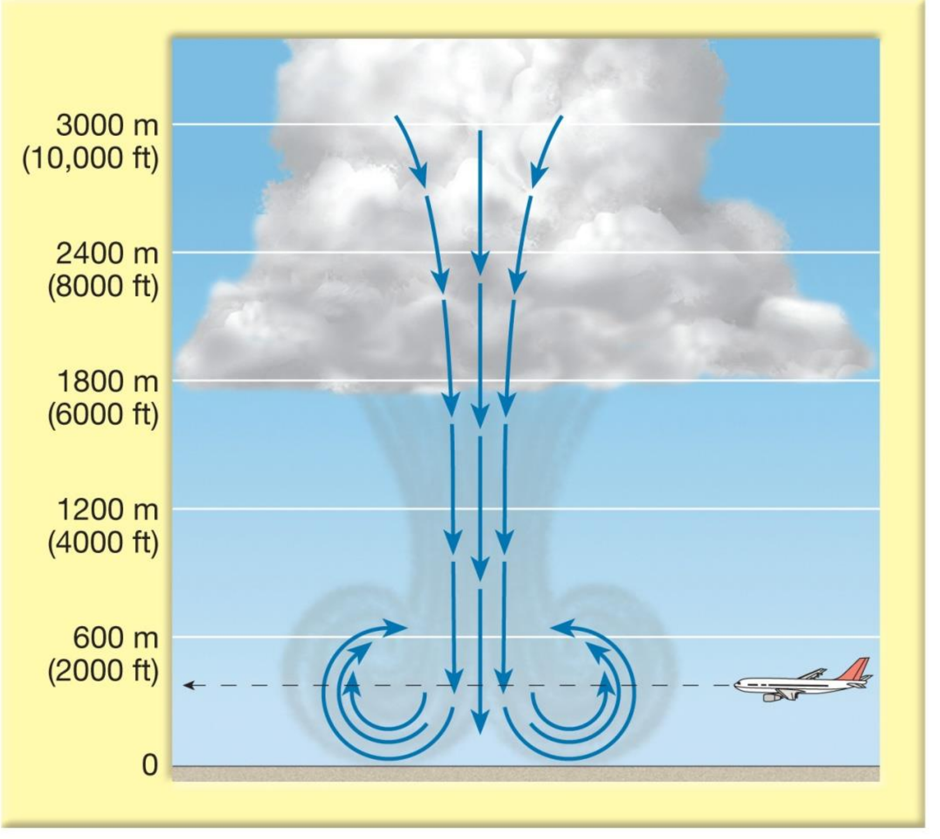
(a)

Source: Landsat Photograph of rolling cumulus clouds.

- Cumulus stage
  - Differential Heating
  - Thermals produce fair-weather cumulus clouds
  - Weak updrafts that initially "topple"
    - Turkey towers
  - This mechanism humidifies the region just above the surface (vertical mixing)

- Mature Stage: Characterized by well defined updrafts and downdrafts

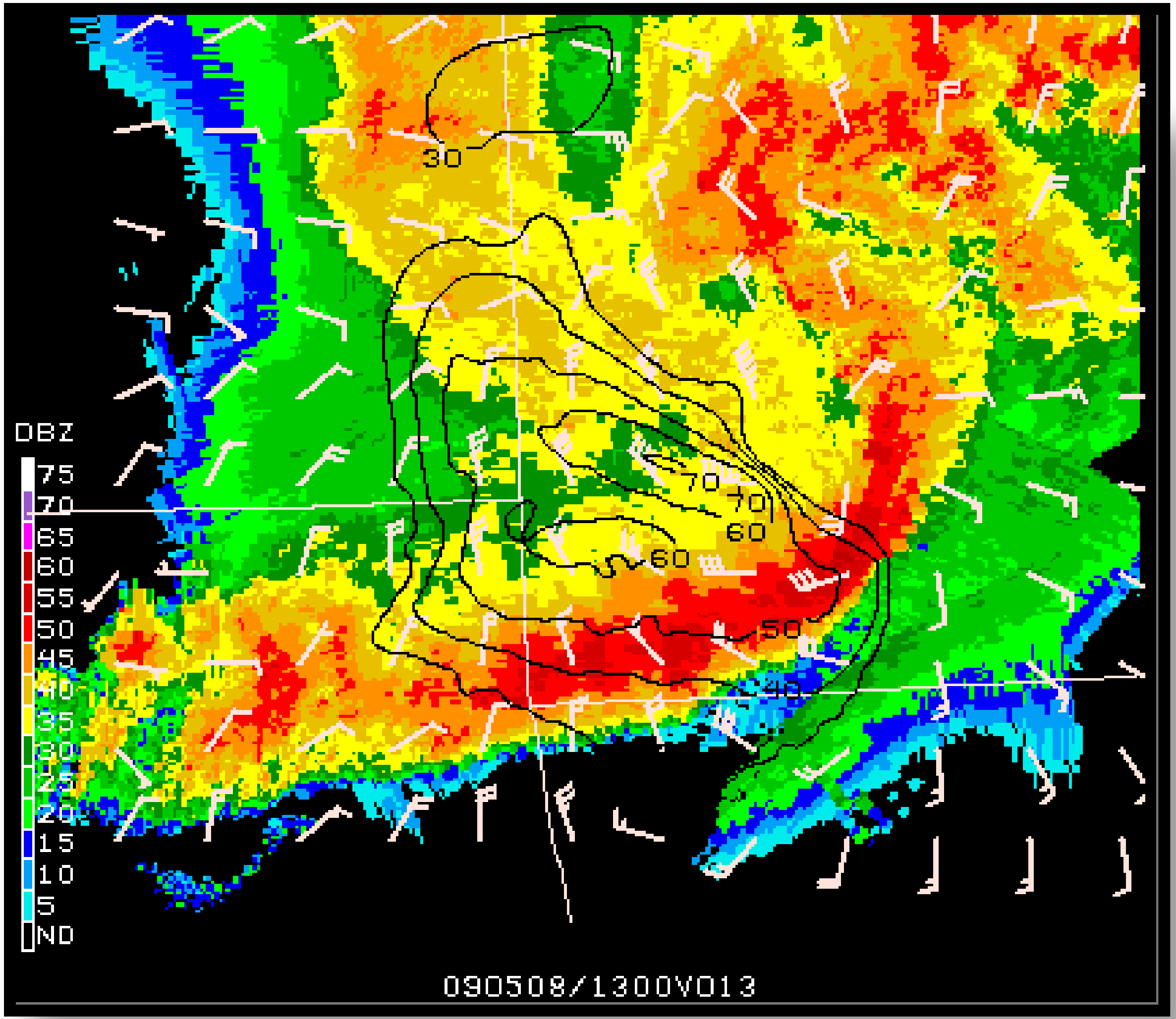
- Mature Stage
  - Characterized by well defined updrafts and downdrafts
  - **Downdraft is significantly enhanced through entrainment**
    - Cold dry air aloft is heavy; is pulled into the downdraft and evaporates some of the moisture which has a cooling effect, thus intensifying the downward
      motion



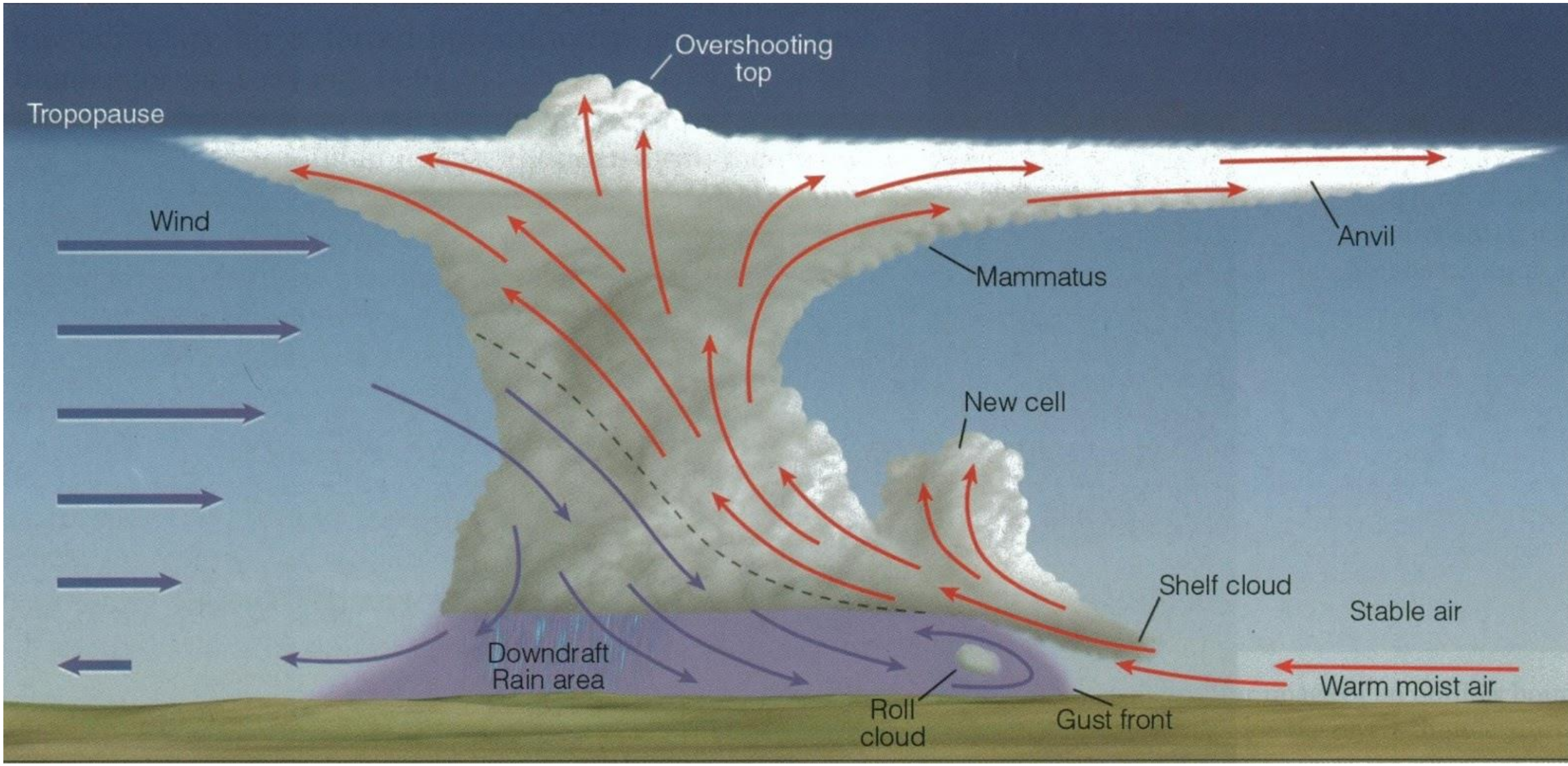
Microburst
Downdraft

- Mature Stage: Microburst downdraft

- Mature Stage: Gust fronts and bow echoes
  - Thunderstorm begins to become outflow dominant (the downdraft)
  - Entrainment causes the structure to evaporate
  - Heavy rain and hail cause the leading edge of the storm to bow outward
    - Gust front
    - Bow echo



Source: http://www.norman.noaa.gov/2009/05/anatomy-of-a-well-forecast-bow-echo/


Overshooting top
Tropopause
Wind
Anvil
Mammatus
New cell
Shelf cloud
Stable air
Downdraft
Rain area
Warm moist air
Roll cloud
Gust front

Gust Front

Gust Front of an outflow dominant storm

Source: MJD – Yankton, SD.

Shelf Cloud: An outflow dominant storm

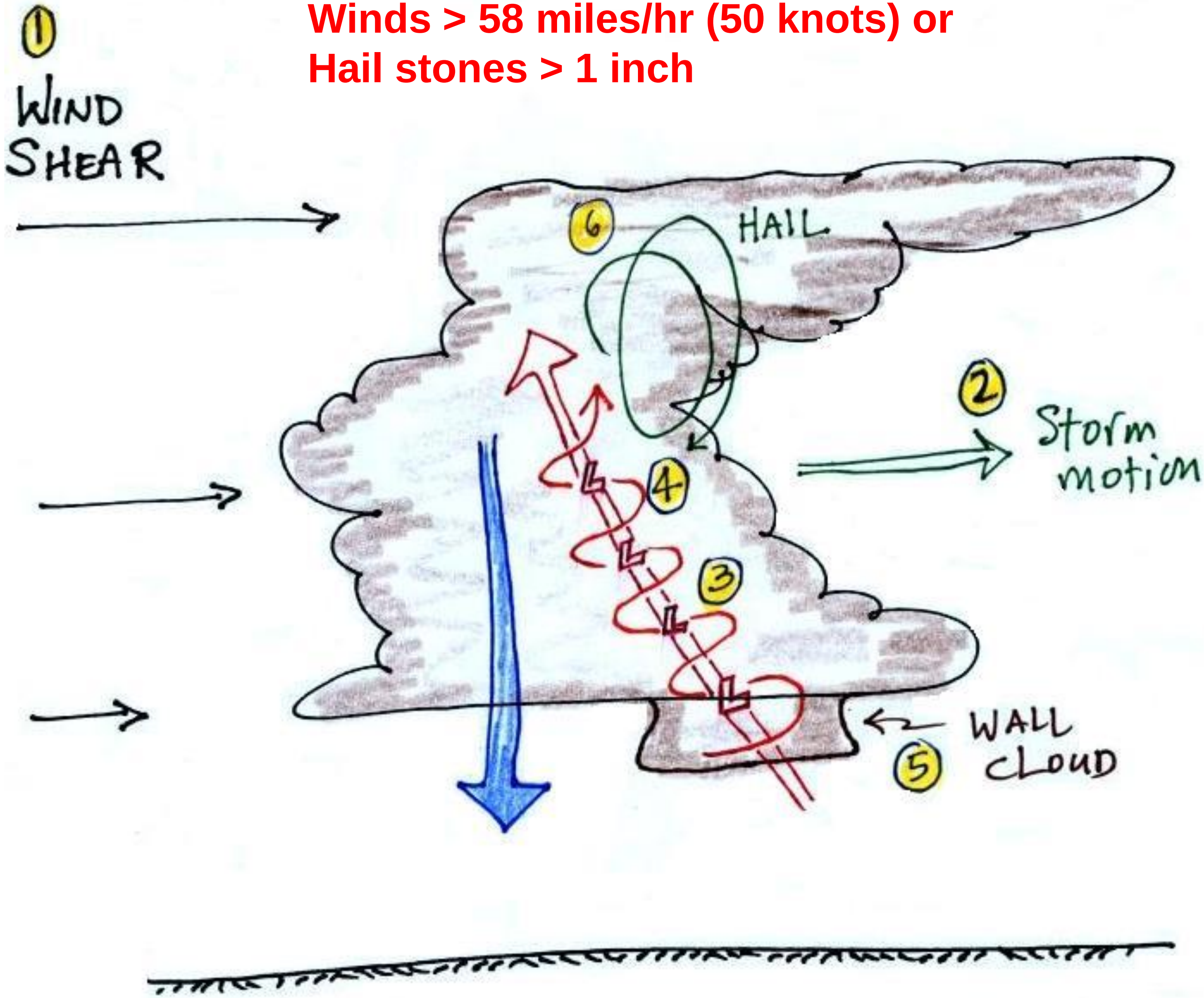
Thunderstorm stages of development (cont'd)

- **Dissipating Stage**
  - Updraft is choked with cold outflows
  - Anvil begins to "sag": Mammatus clouds

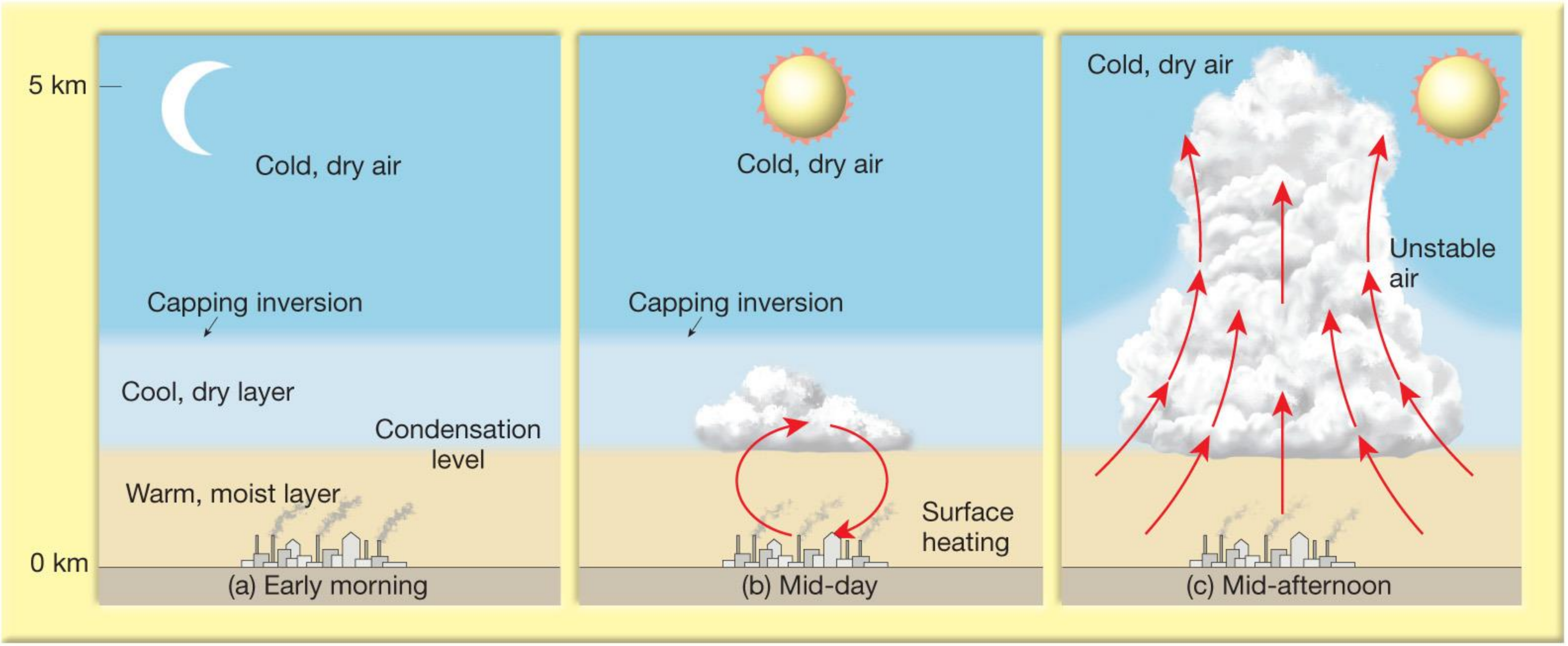
Mammatus Clouds

Severe Thunderstorms

Winds > 58 miles/hr (50 knots) or
Hail stones > 1 inch



The Cap! Where is the top of the boundary layer?

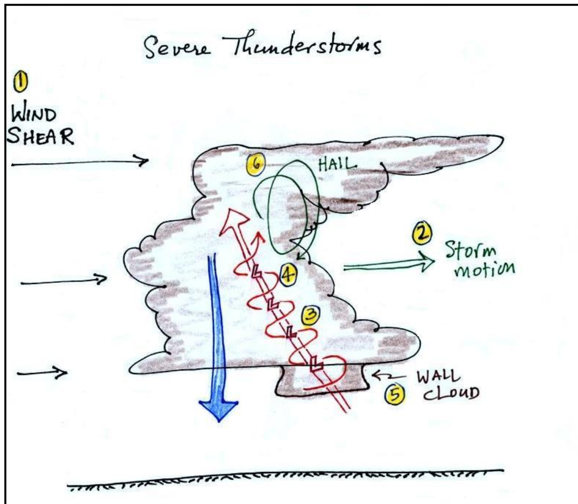


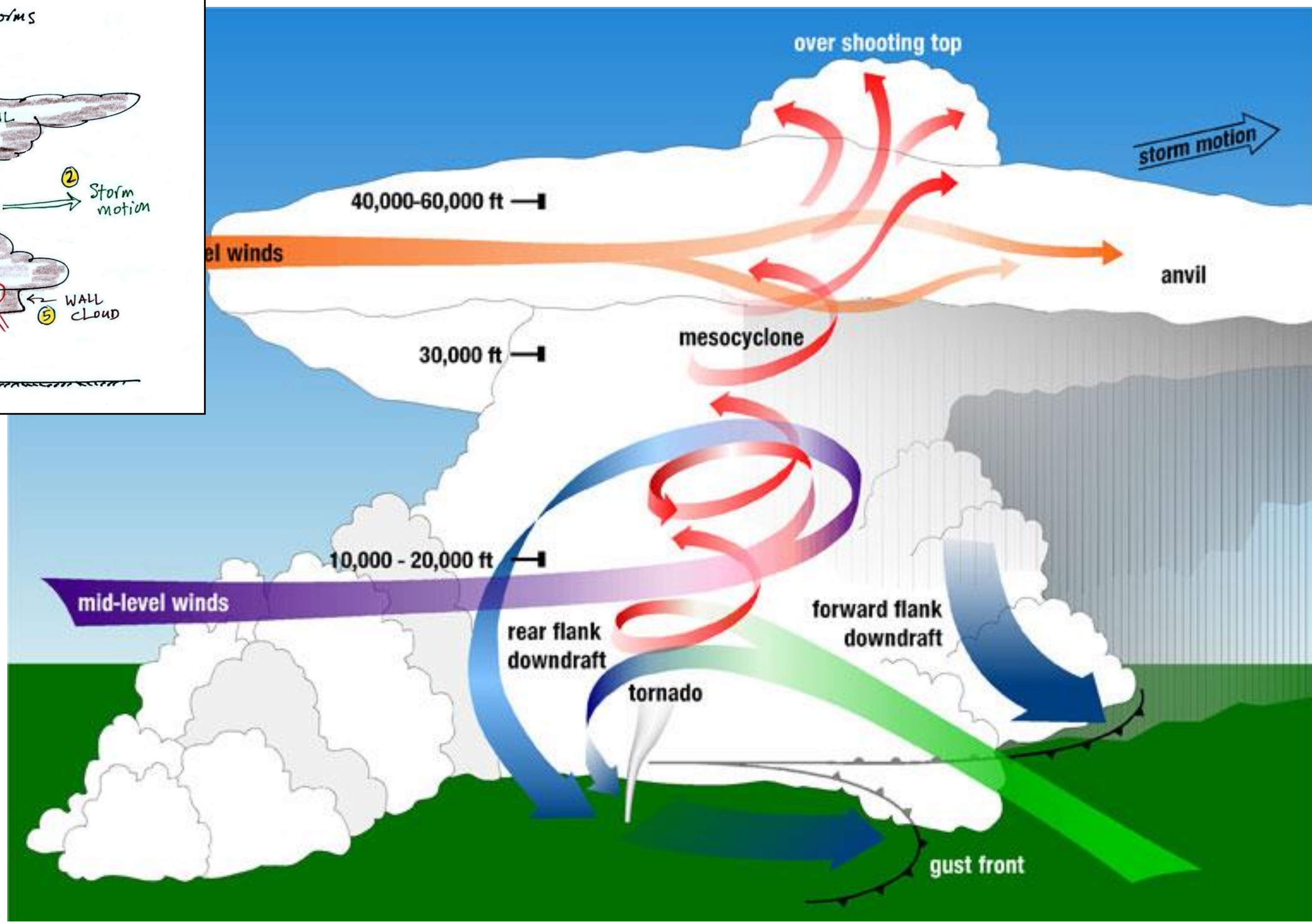
Temperature Inversion Enhances Development of Severe Thunderstorms

Supercell Thunderstorms

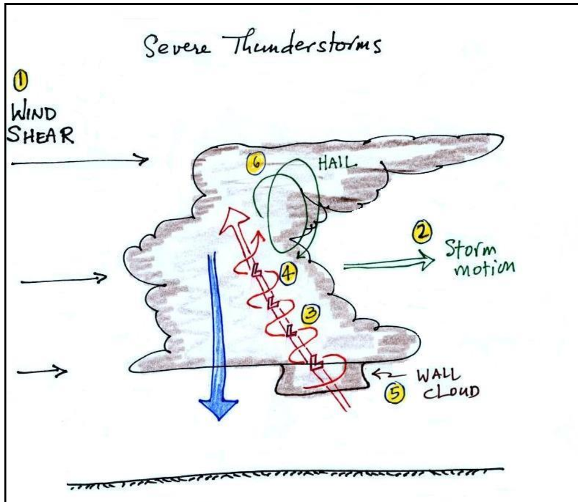
- Extend 65,000 ft (20km) height, 12-30 miles (50km) in diameter, persist for several hours.
- It is believed supercells account for:
  - Nearly all significant tornadoes
  - Almost all significant hail (i.e. > 2.00”)
  - Much of the significant wind damage each year.
- These long-lived, persistent updrafts come in many shapes and sizes
  - Low Precipitation
  - High Precipitation
  - Classic

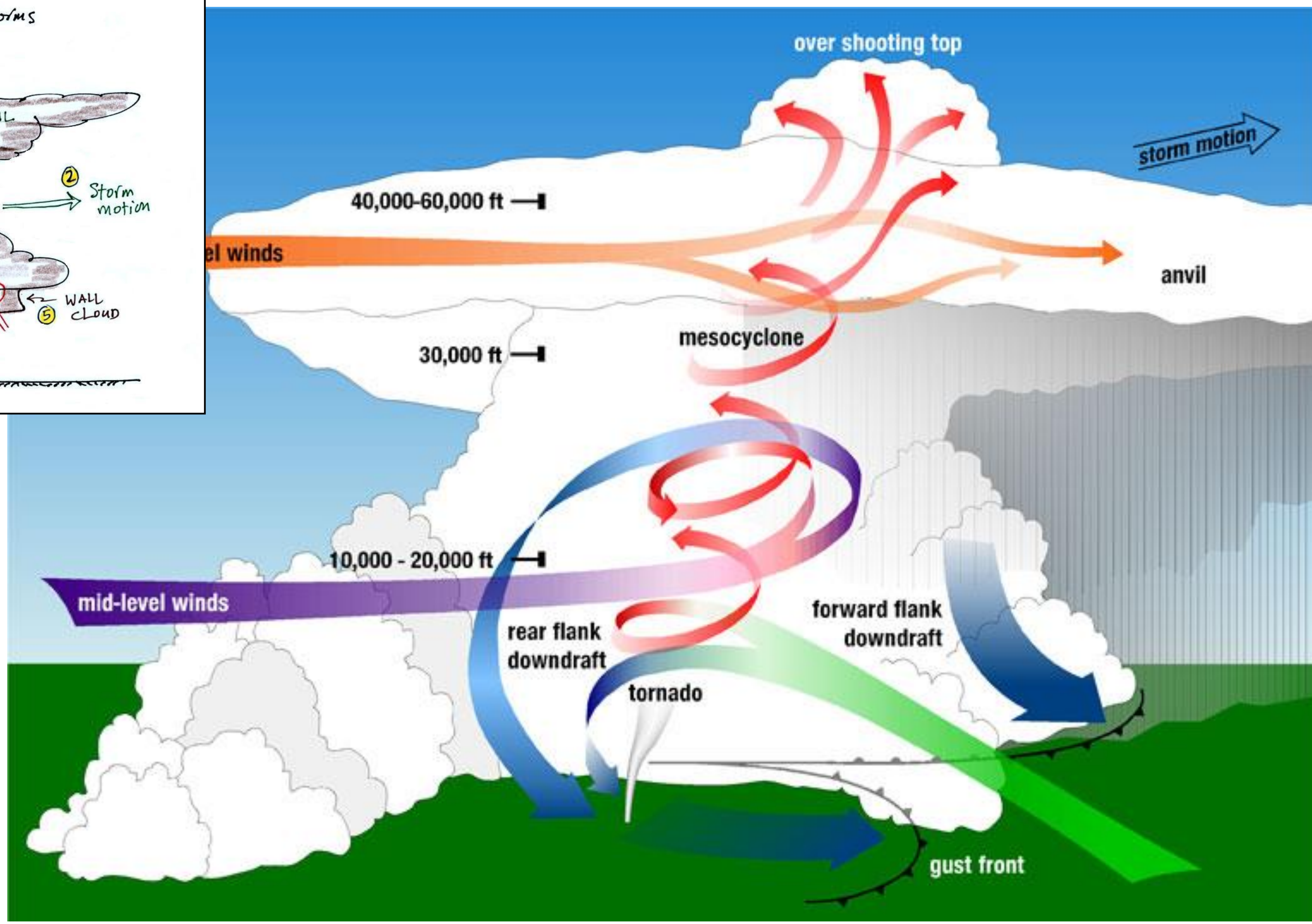
Severe storms are more likely to form when there is vertical wind shear. Wind shear (pt 1) is changing wind direction and/or wind speed with distance. In this case, the wind speed is increasing with increasing altitude, this is vertical wind shear.



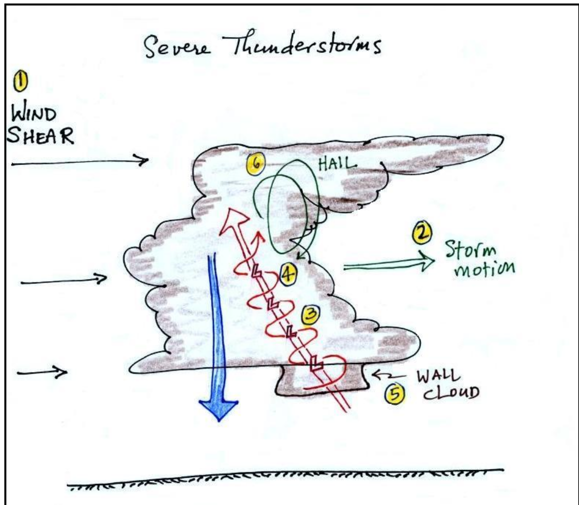


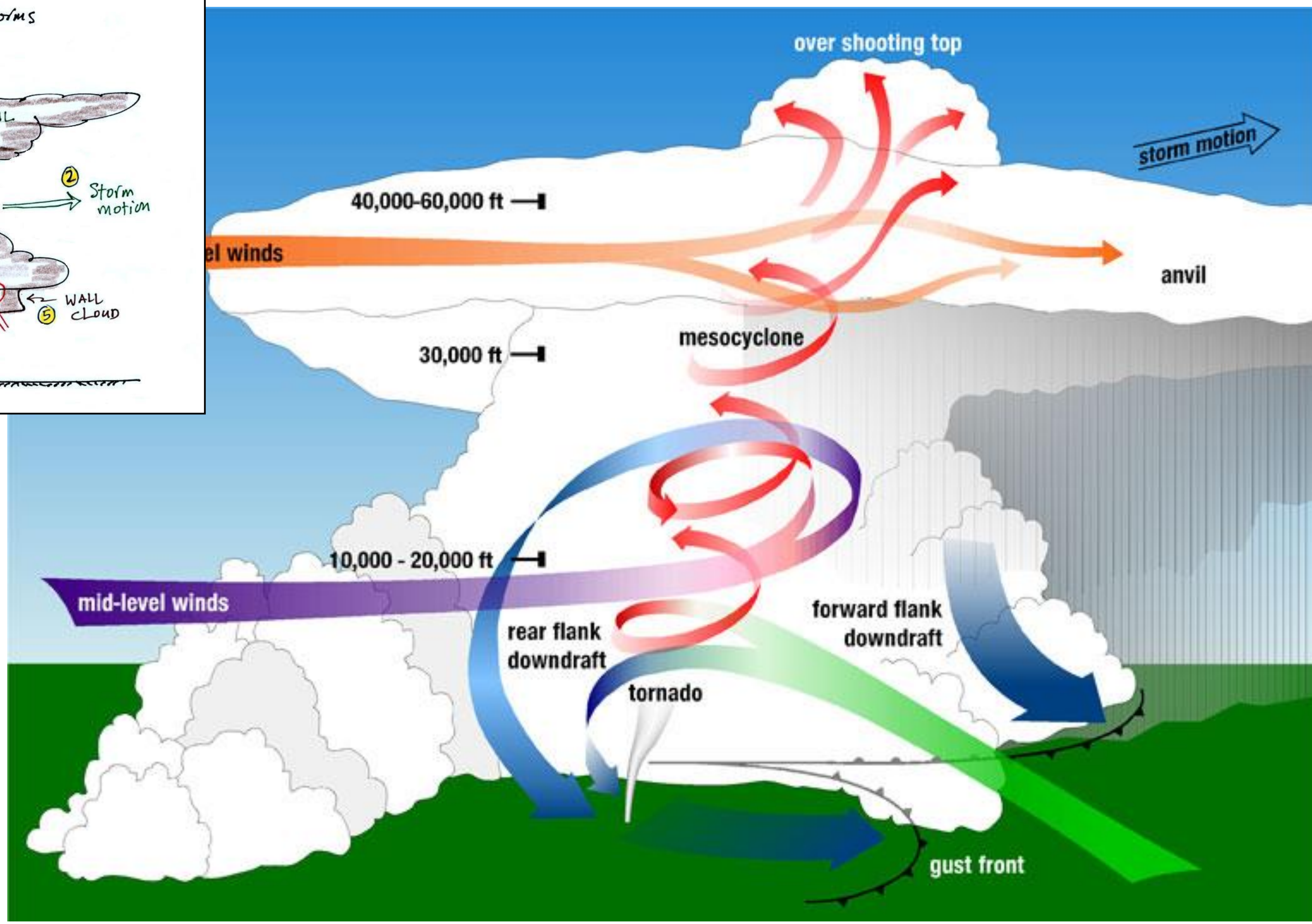
Wind shear and storm movement result in tilted updrafts (pt 3). The updraft and downdraft coexist, can last longer and get larger and stronger than an air mass thunderstorm.





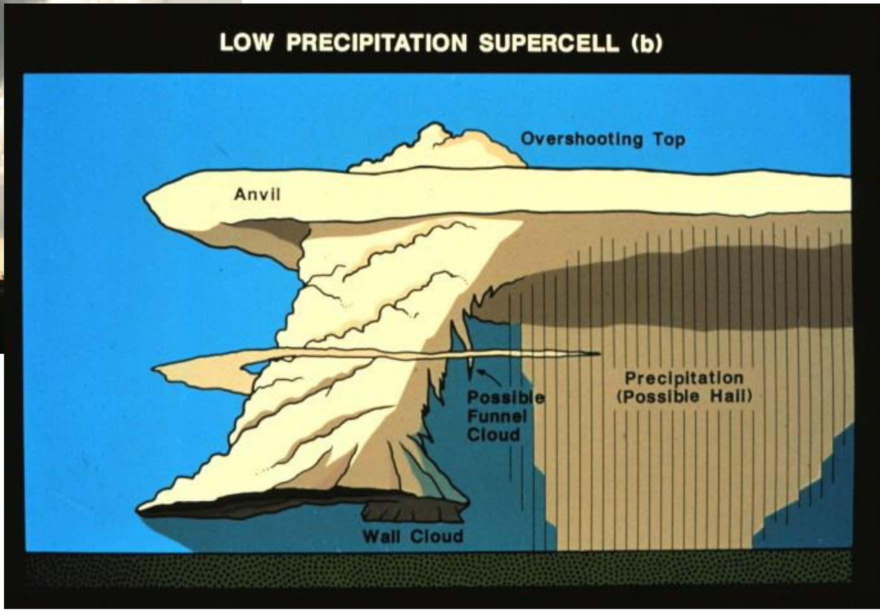
Wind shear will also rotate the tilted updrafts (**mesocyclone**). Low pressure in the core of the mesocyclone creates an inward pointing pressure gradient force needed to keep the updraft winds spinning in circular path (low pressure also keeps winds spinning in a tornado).





Low Precipitation Supercell

If the storm relative winds at mid-upper levels are excessive: precipitation is carried too far downwind, inhibiting rain-cooled outflow formation on the rear flank - LP supercell



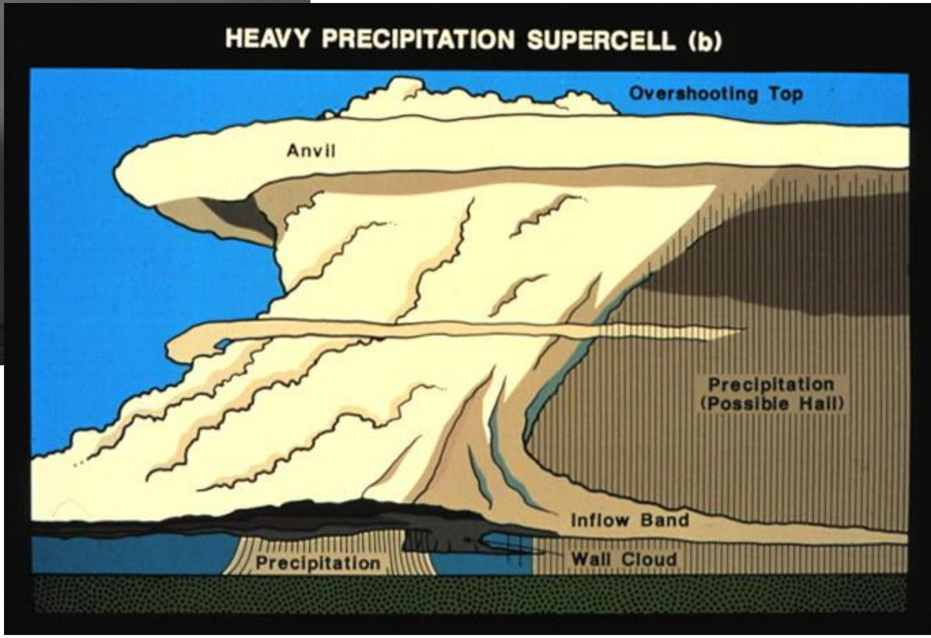
Source: Jeff Evans, Storm Prediction Center

High Precipitation Supercell

Source: Jeff Evans, Storm Prediction Center

IF THE STORM RELATIVE WINDS AT MID UPPER LEVELS ARE WEAK :

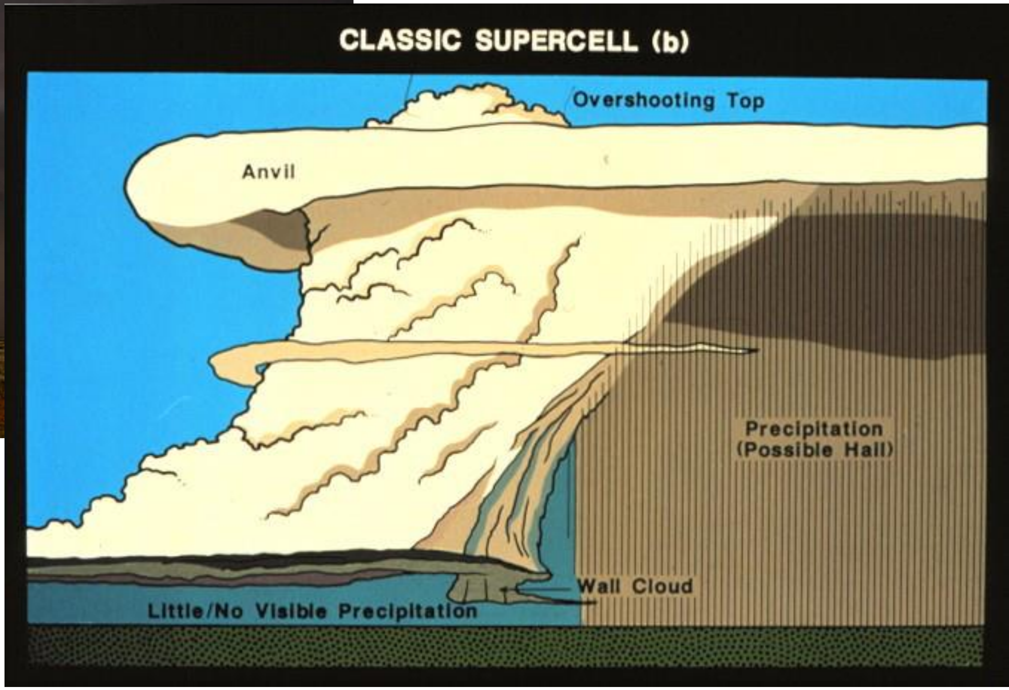
- A large amount of precipitation will form near/in the updraft and will wrap around the mesocyclone- HP supercell
- HP supercells tend to be outflow dominated. rain-cooled outflow undercuts the mesocyclone limiting the potential for long-lived tornadoes.
- very large hail and bow echo evolution common.



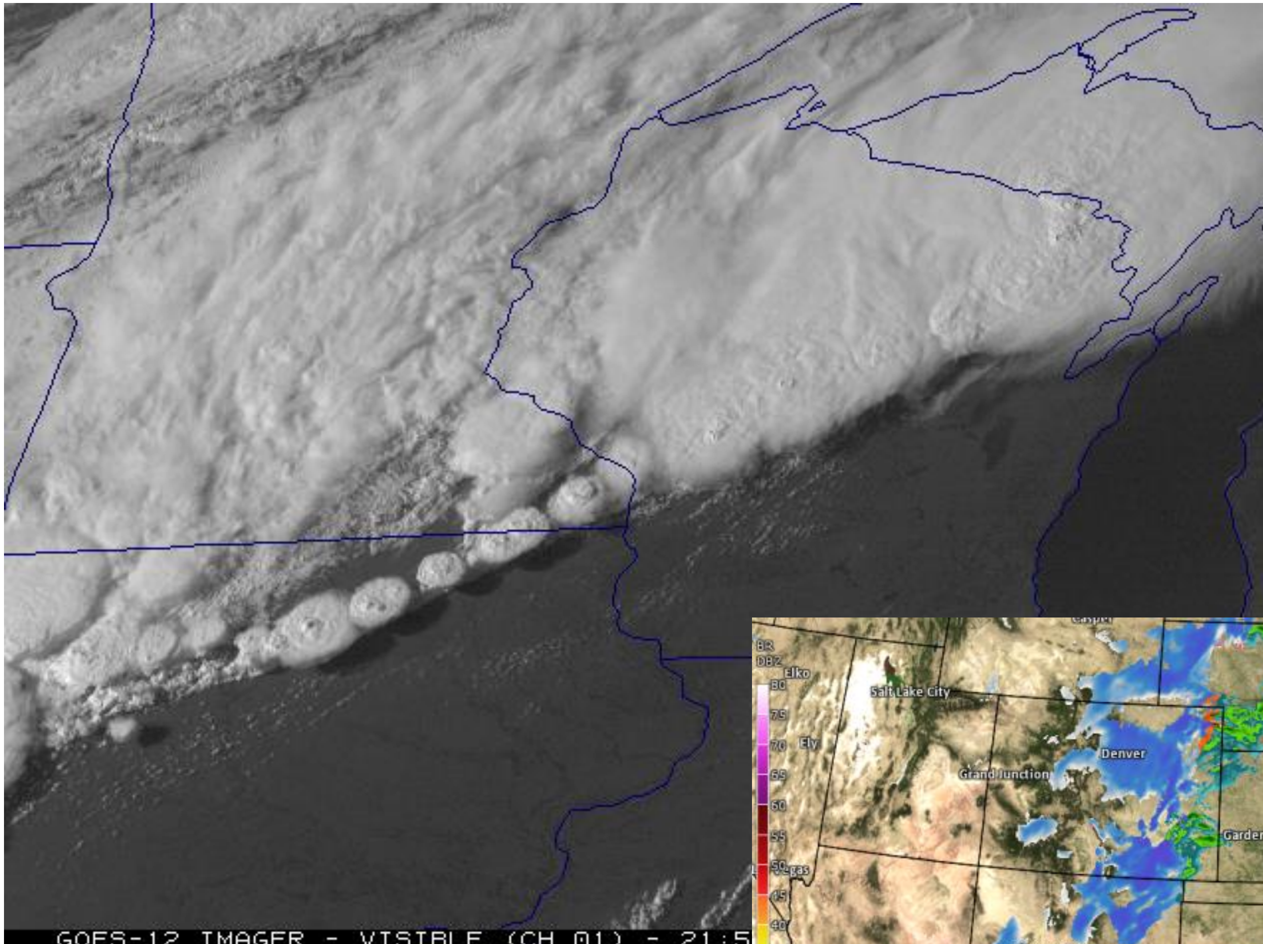
Classical Supercell

Source: Jeff Evans, Storm Prediction Center

- Long-lived and/or multiple tornadoes are most likely when there is a balance between low-level inflow and outflow such that the mesocyclone does not occlude rapidly- classic supercell



Linear mesoscale complex



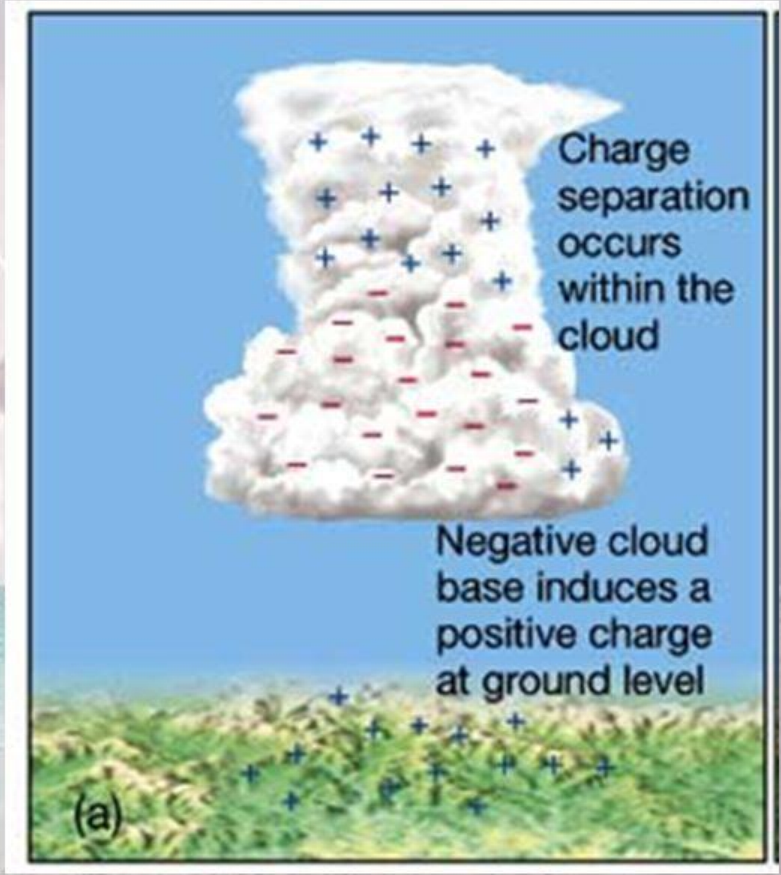
Lightning streak/flash is made of several individual strokes that ionize the atmosphere (3-4, 50 millisecond spacing)

Rapid expansion of air (>33,000 ^{o}C) creates the sound wave **Thunder**

Lightning Formation – Charge Separation

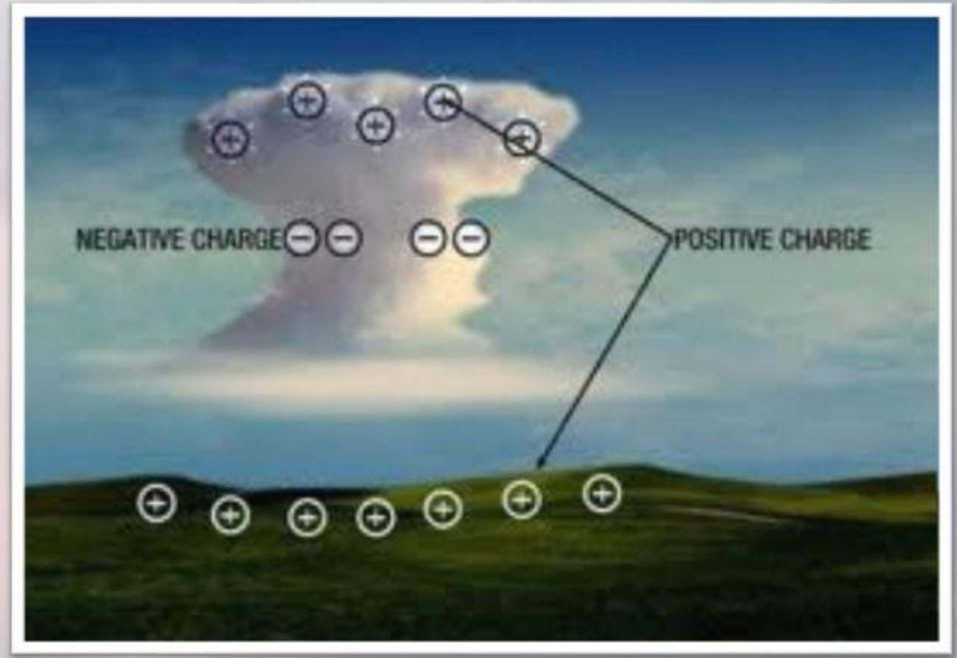
- We don't exactly know why it happens

- One theory:
  - **Hail stones** tend to have a **warmer surface** than ice crystals
  - When warm hail collides with colder ice, **electrons transfer from ice to hail**
  - **Hail (-) is bigger and heavier and settles toward the bottom of the cloud**
  - Smaller (+) ice crystals are lofted to the top.



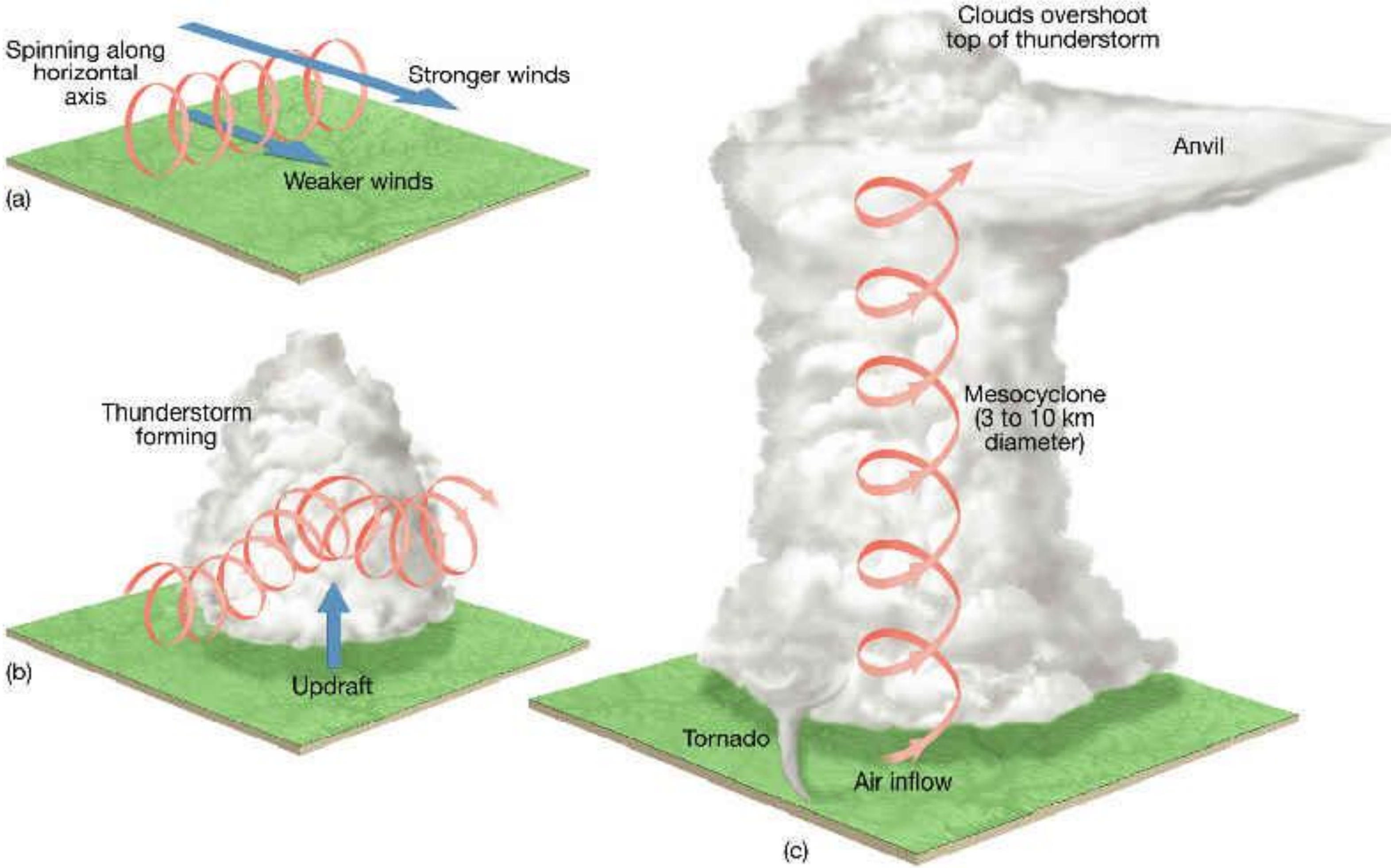
Lightning

- May occur:
  - Between cells in the same storm
    - inter-cloud lightning
  - Within a cloud
    - intra-cloud lightning
  - Cloud to air
  - Cloud to ground (CG)



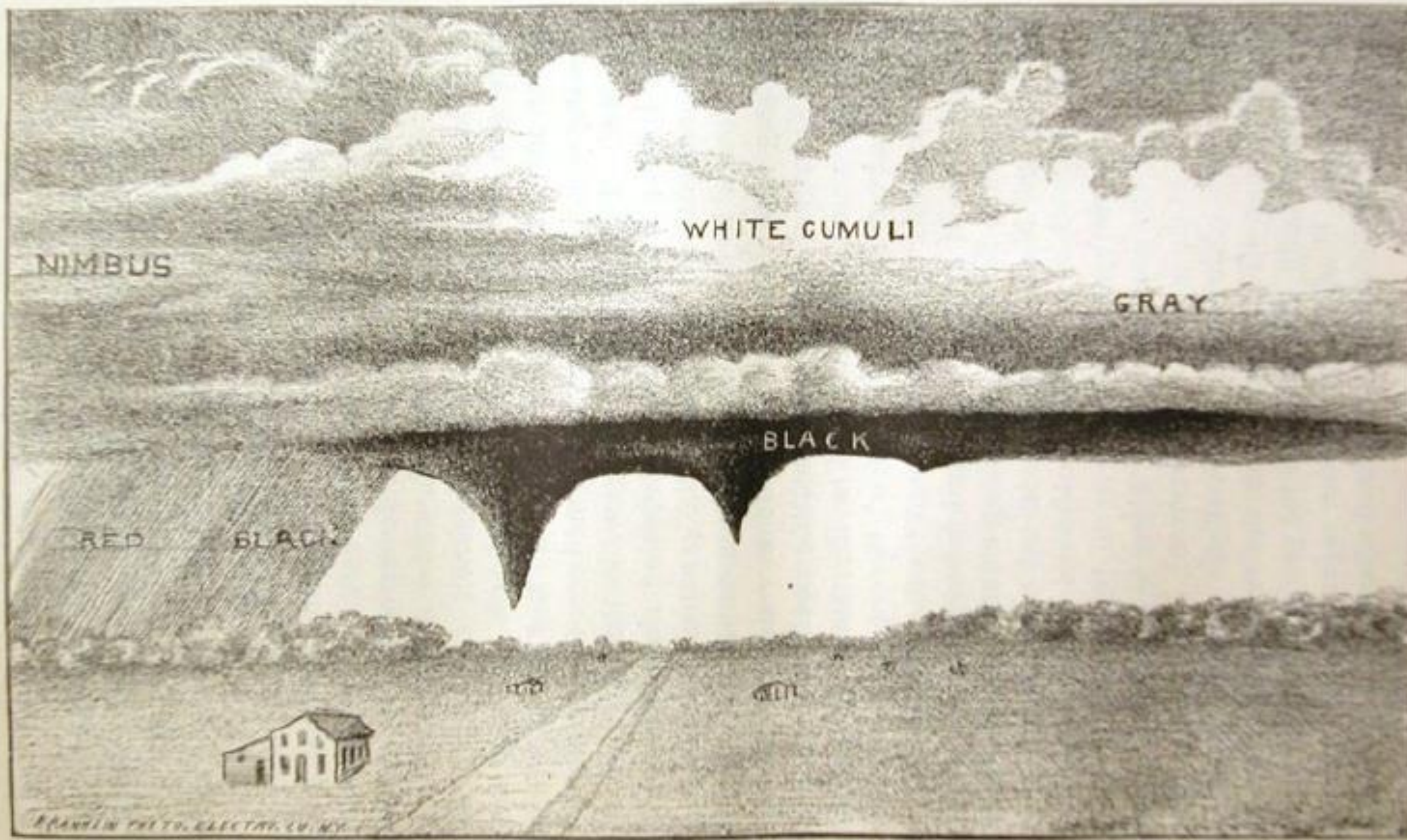
- Lightning forms when a charge separation occurs in a cloud
  - The earth is trying to equalize the electrical difference
  - **Negative charges want to flow to the ground.**

Tornados



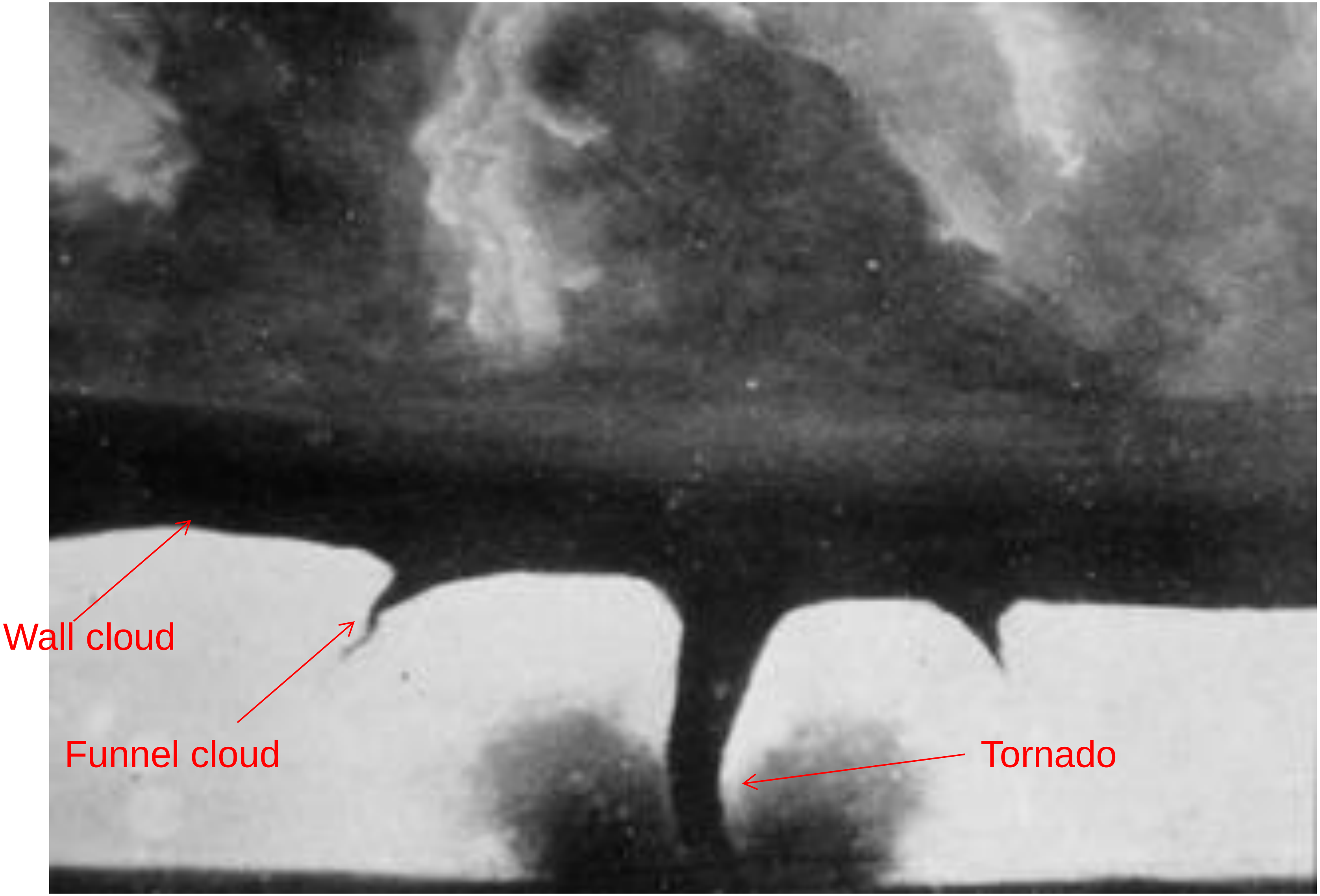
Tilting and stretching of the mesocyclone draws the circulation closer to the axis of rotation, increasing the wind speeds

Newtonia, MO., Aug., 1882, about 6pm from a rough pencil sketch made from memory

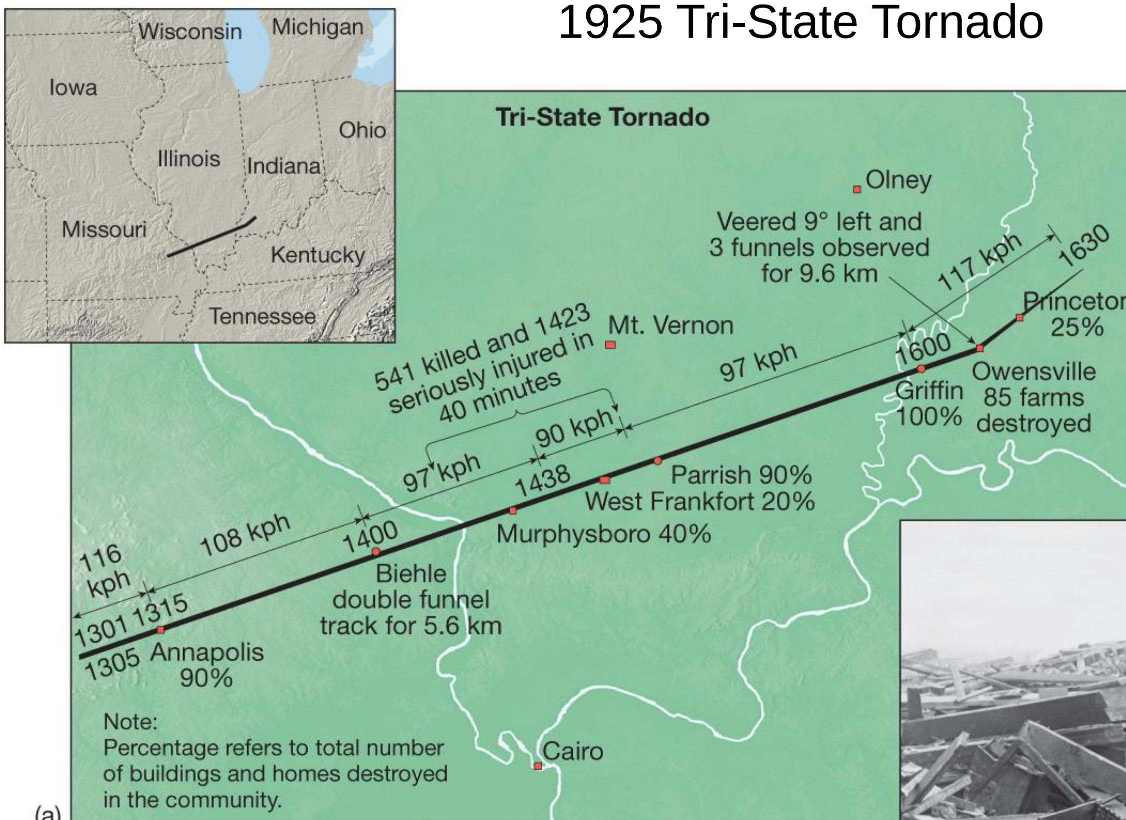


Newtonia, Mo., Aug., 1882, about 6 p. m. From a rough pencil sketch made from memory.

The earliest known photograph of a tornado 1884



1925 Tri-State Tornado



(a)


(b)

“Tornado” was banned from forecasting in 1885!

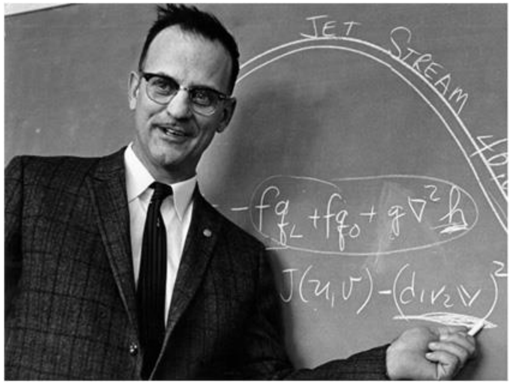
- The law was changed in 1939, but not implemented until the 1950s

Source: The Wizard of Oz, 1939.

The Wizard of Oz popularizes tornadoes, but never uses the word in the movie!

THE FIRST OPERATIONAL TORNADO FORECAST (!)

establishing the Severe Local Storms Unit



ERNEST J. FAWBUSH, *Colonel*

Airplanes thrown about like toys by the tornado that, on March 20, 1948, struck Tinker Air Force Base, Oklahoma

ROBERT C. MILLER, *Colonel*

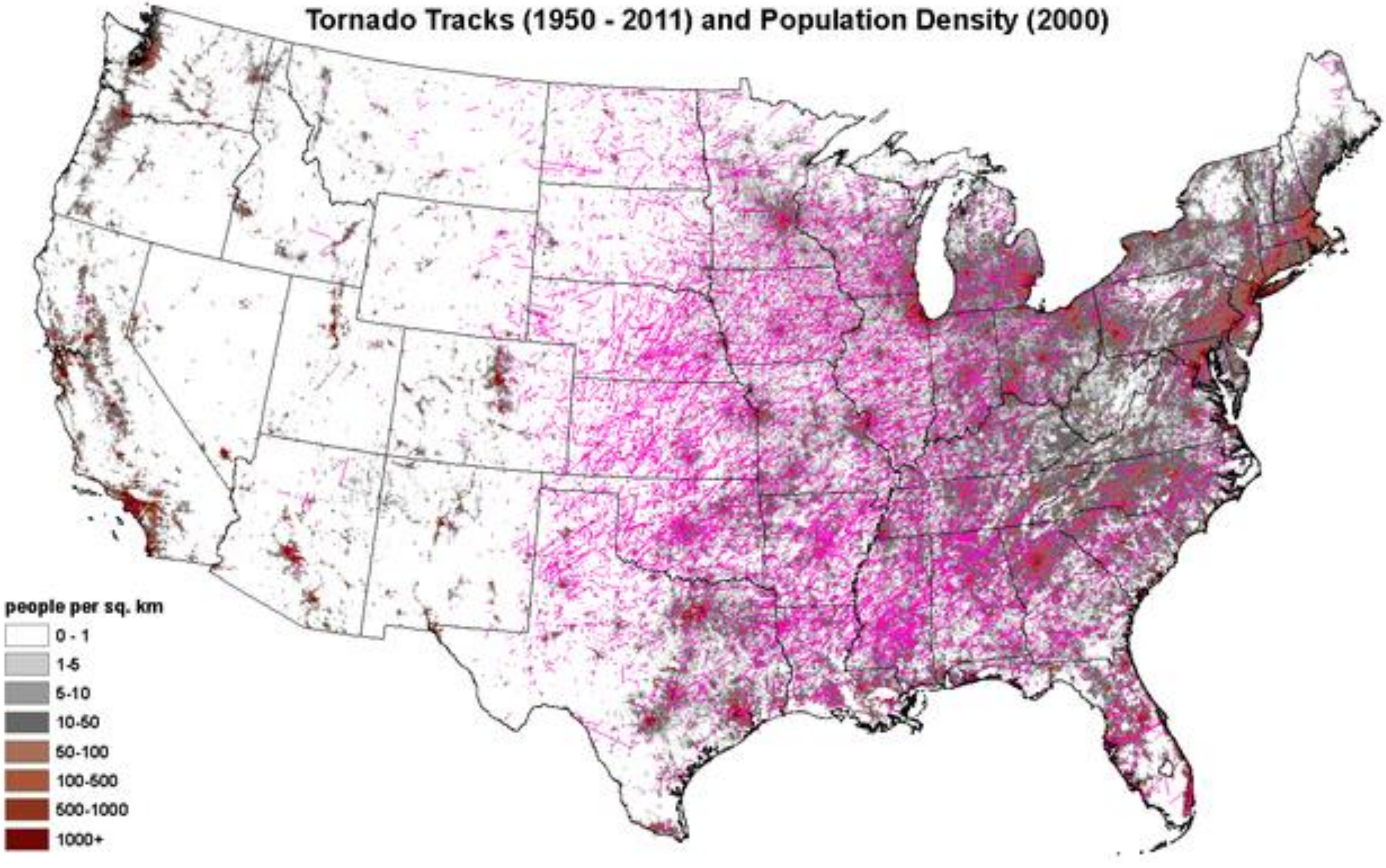
Source: *http://www.nssl.noaa.gov/GoldenAnniversary/Historic.html.*
Doswell, Charles A. A Historical Overview of Severe Convective Storms Research, E-Journal of Severe Storms Meteorology, Vol 2, No 1 (2007)

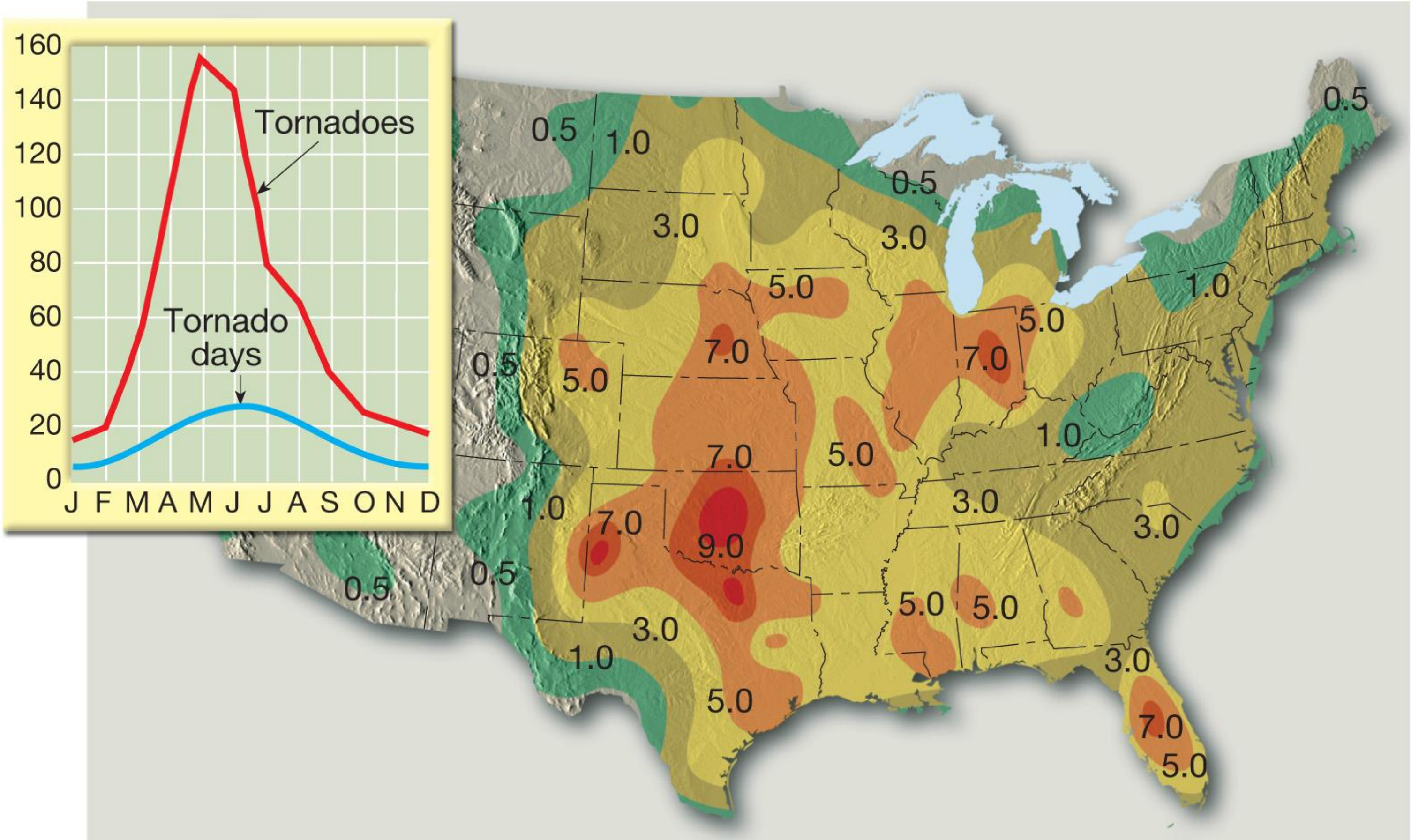
Ted Fujita and Photogrammetric Analysis

- Known for his Fujita scale
- Known to be the discover of microburstsand multivortices
- Was the first to use photographs and films of tornadoes to gather numerical data

EF-Scale Number	3-Second Gust Speed (mph)	Damage Descriptions Based on the Typical Construction of One- and Two-Family Residences
EF0	65-85	Beginning of visible damage; loss of roof covering material, gutters, and/or awning; loss of vinyl or metal siding.
EF1	86-110	Broken glass in doors and windows; uplift of roof deck and loss of significant roof covering material; collapse of chimney; garage doors collapse inward; failure of porch or carport.
EF2	111-135	Entire house shifts off foundation; large sections of roof structure removed; most walls remain standing, however top floor exterior walls collapse.
EF3	136-165	Most interior walls of top story collapsed; most walls collapsed in bottom floor, except small interior rooms.
EF4	166-200	Total destruction of entire building.
EF5	>200	

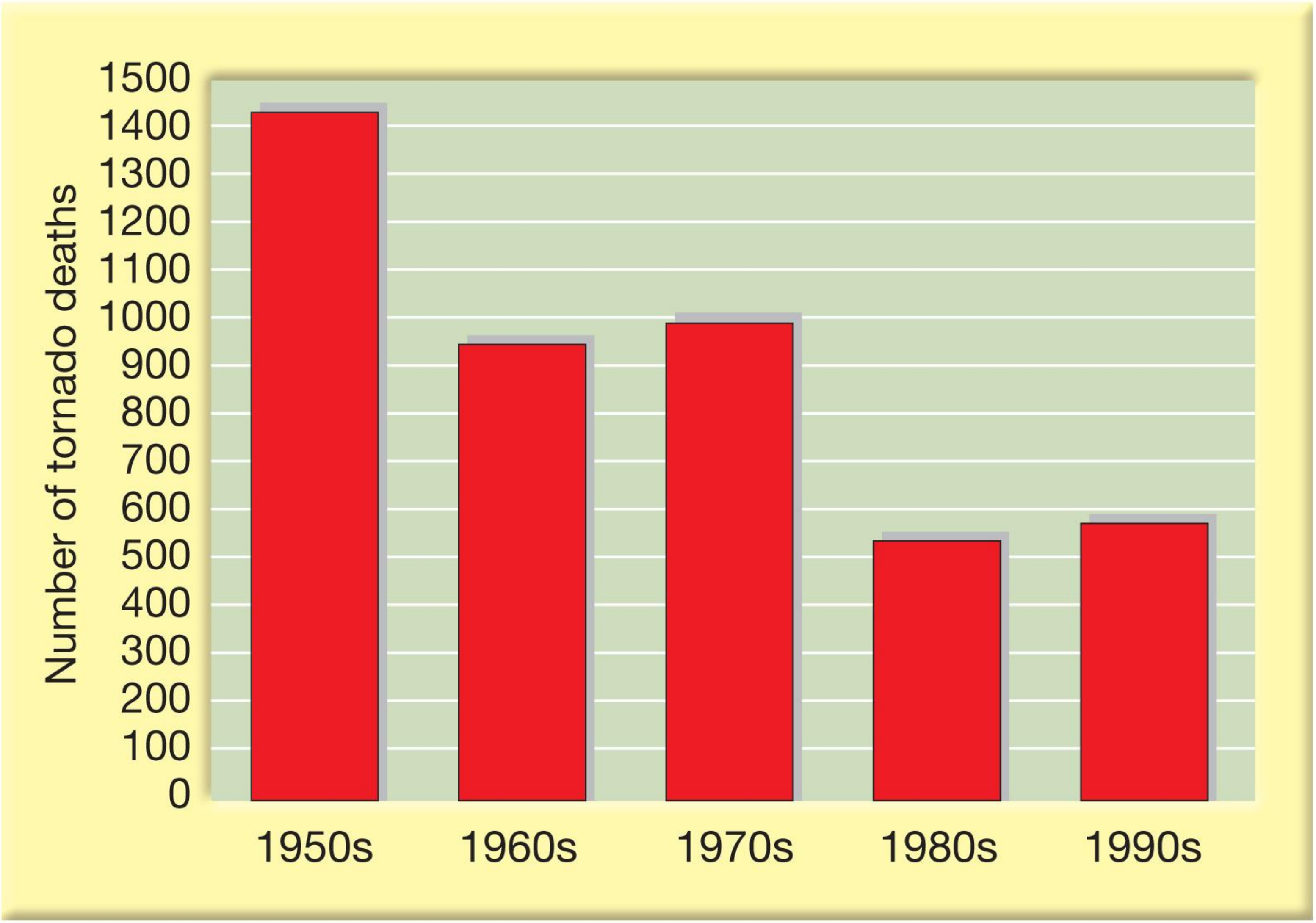
Source: http://www-news.uchicago.edu/releases/98/981120.fujita.shtml
http://www.spc.noaa.gov/faq/tornado/#Research

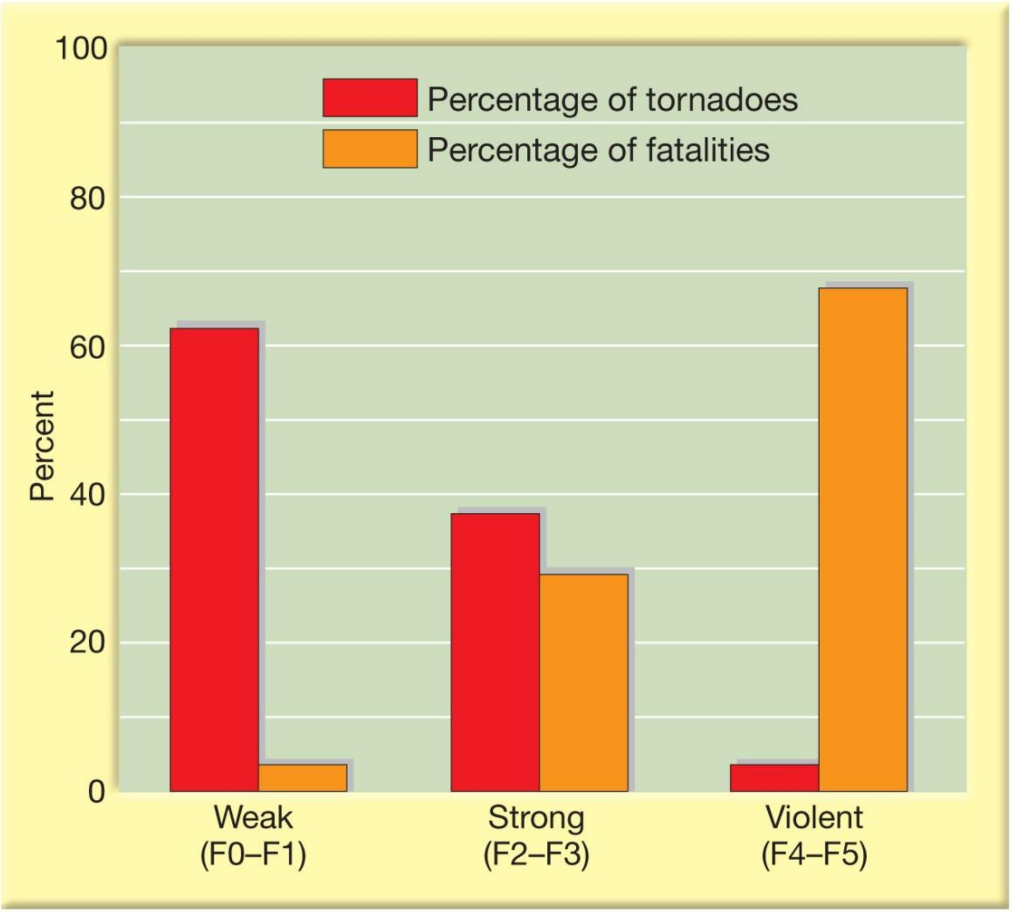

Tornado Tracks (1950 - 2011) and Population Density (2000)
people per sq. km
0 - 1
1-5
5-10
10-50
50-100
100-500
500-1000
1000+



Annual Average Incidence of Tornadoes in the United States; Average Number of Tornadoes and Tornado Days each Month

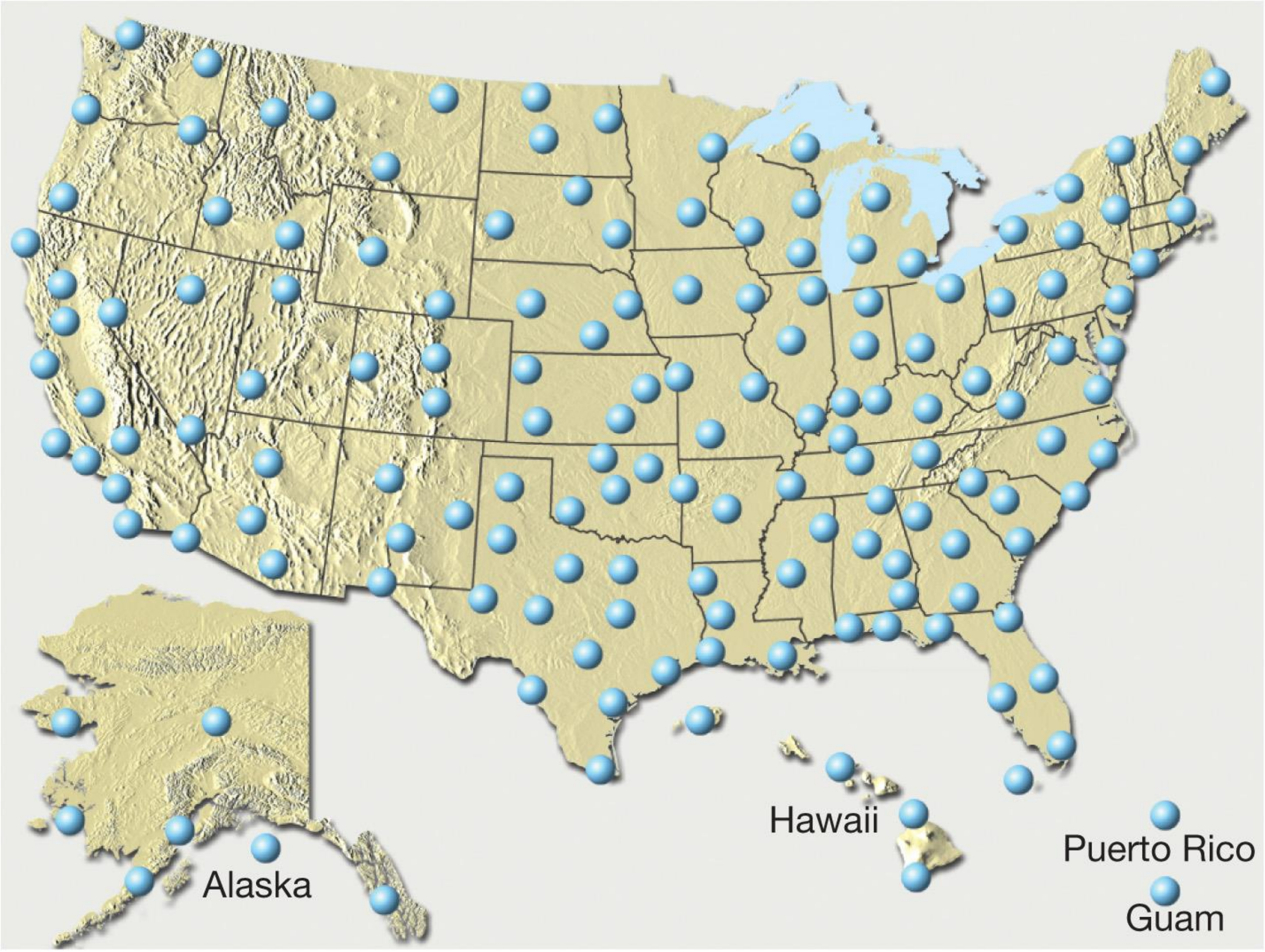
Tornado Deaths over 50 Years





Force of Tornadoes Compared to Fatalities

Jon Schaefer director of the NOAA/NWS Storm Prediction Center, Norman, Oklahoma reported in an article for USA Today that the energetic output of a tornado is on the order of 10,000 kilowatt hours, “while a hurricane contains 10,000,000,000 kilowatt-hours. (For comparison, a Hydrogen Bomb also contains 10,000,000,000 kilo-watt hours.) However, because a tornado is so much smaller than a hurricane, the energy density (energy per unit volume) of a tornado is about 6 times greater for a tornado than for a hurricane. In terms of energy density, a tornado is the strongest of nature's storms.” (http://www.usatoday.com/weather/wtwistqa.htm)



(d)

Locations of National Weather Service Stations
http://www.weather.gov/