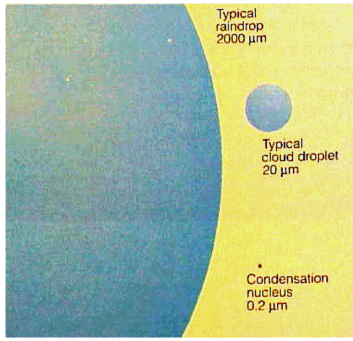
Precipitation Formation

How can precipitation form from tiny cloud drops?

1. Warm rain process
2. The Bergeron (ice crystal) process
3. Ice multiplication



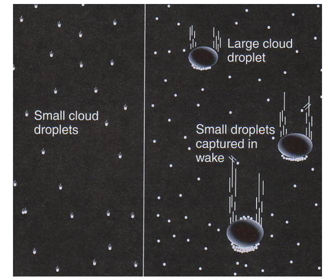
How many 20 µm cloud drops does it take to make a 2000 µm rain drop?

$V = 4/3pr^3 = pd^3/6$

$(2000/20)^3$ = **1,000,000**

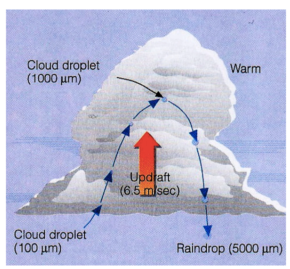
Rain formation in warm clouds (no ice)

- In a supersaturated environment, activated cloud drops grow by water vapor condensation
  - It takes many hours for the cloud drop to approach rain drop size
- Collisions between cloud drops can produce large rain drops much faster through coalescence
  - Collisions occur in part due to different settling rates of large and small drops
  - Not all collisions result in coalescence
- Rain formation favored by
  - Wide range of drop sizes
  - Thick cloud
  - Fast updrafts



Rain formation in warm clouds

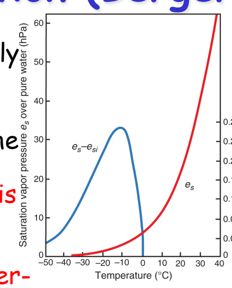
- Capture of a cloud/rain drop in a cloud updraft can give it more time to grow
- The drop falls at a fixed speed relative to the air, not the ground
- Large drops fall faster

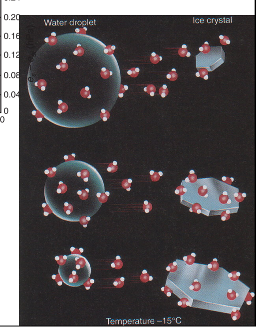


DIAMETER (µm)	TERMINAL VELOCITY m/sec	ft/sec	TYPE OF PARTICLE
0.2	0.0000001	0.0000003	Condensation nuclei
20	0.01	0.03	Typical cloud droplet
100	0.27	0.9	Large cloud droplet
200	0.70	2.3	Large cloud droplet or drizzle
1000	4.0	13.1	Small raindrop
2000	6.5	21.4	Typical raindrop
5000	9.0	29.5	Large raindrop

Ice crystal growth by vapor deposition (Bergeron process)

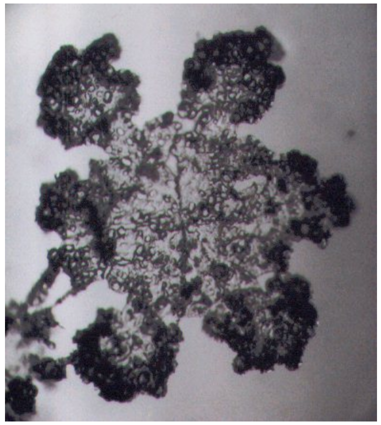
- Ice binds water molecules more tightly than liquid water
  - For temperatures less than 0°C, the saturation vapor pressure over ice is **less** than the saturation vapor pressure over super-cooled water
- This leads to evaporation of water from supercooled cloud drops and deposition onto ice crystals





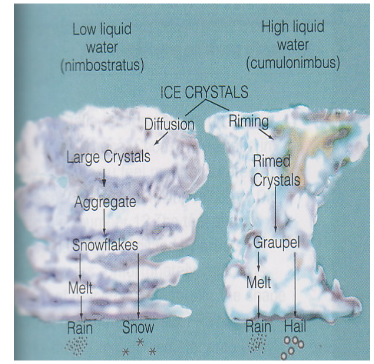
Ice crystal growth by accretion

- Ice crystals fall faster than cloud drops
- Crystal/drop collisions allow ice crystals to capture cloud drops
  - The supercooled drops freeze upon contact with the ice crystal
  - This process is known as accretion or riming
- Extreme crystal riming leads to the formation of
  - Graupel
  - Hail



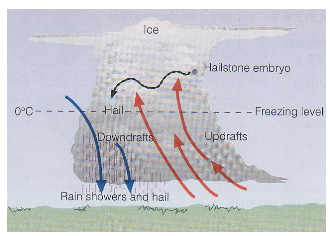
Precipitation in cold clouds

- Low liquid water content promotes diffusion/ deposition growth of large crystals
- High liquid water content promotes riming and formation of graupel/hail
- If the sub-cloud layer is warm, snow or graupel may melt into raindrops before reaching the surface (typical process for summer rain in Colorado)



Hail

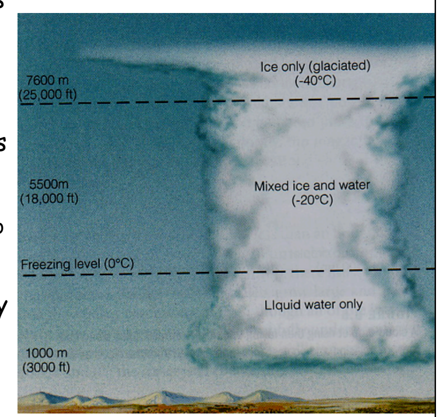
- Hail can form in clouds with
  - High supercooled liquid water content
  - Very strong updrafts decoupled from downdrafts
- Hailstones typically make 2-3 trips up through cloud
- Opaque and clear ice layers form
  - Opaque represents rapid freezing of accreted drops
  - Clear represents slower freezing during higher water accretion rates
  - Layering tells about hailstone history

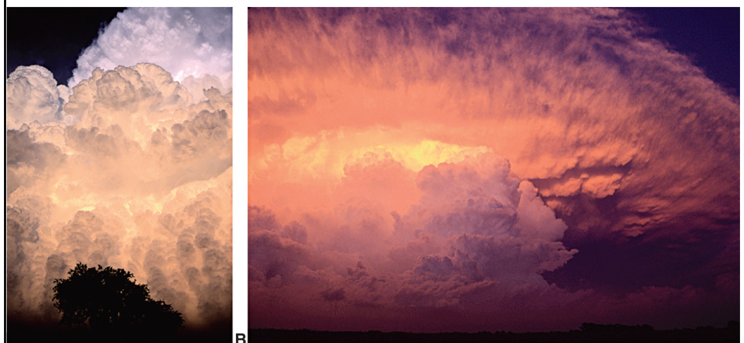


The largest hailstone ever recovered in the United States, a seven-inch (17.8-centimeter) wide chunk of ice almost as large as a soccer ball. It was found in Aurora, Nebraska on June 22, 2003. The hailstone lost nearly half of its mass upon landing on the rain gutter of a house

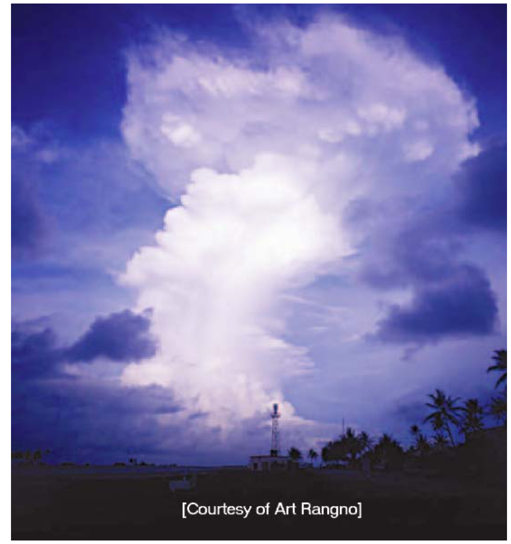
Ice Crystal Processes in Cold Clouds

- Outside deepest tropics most precipitation is formed via ice crystal growth
- *Supercooled* cloud drops and ice crystals coexist for –40° < T < 0° C
  - Lack of freezing nuclei to "glaciate" drops
- Ice crystals can grow by
  - Water vapor deposition
  - Capture of cloud drops (accretion/riming)
  - *Aggregation*





Courtesy of Brian Morganti



Cumulus Clouds & Clear Sky

Figure 7.15

Cumulus to Cumulonimbus

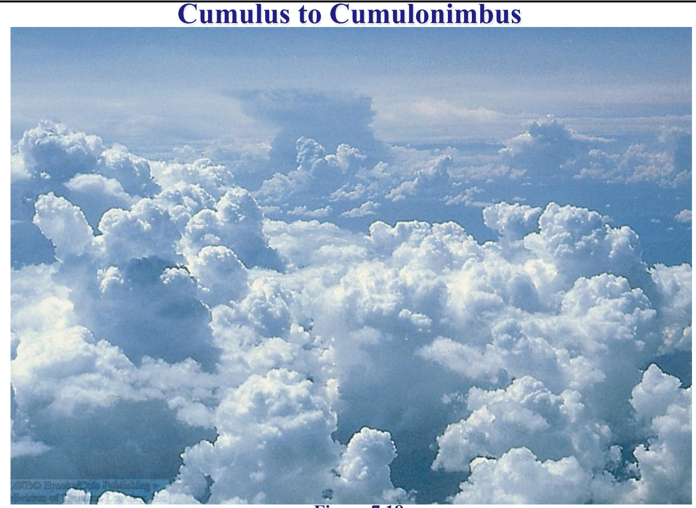
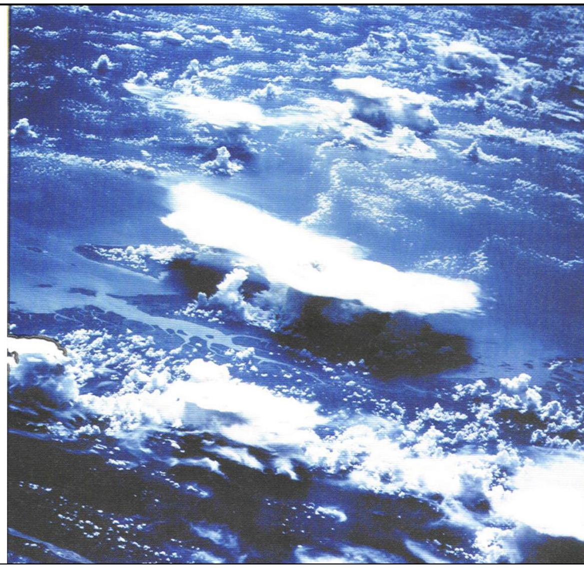
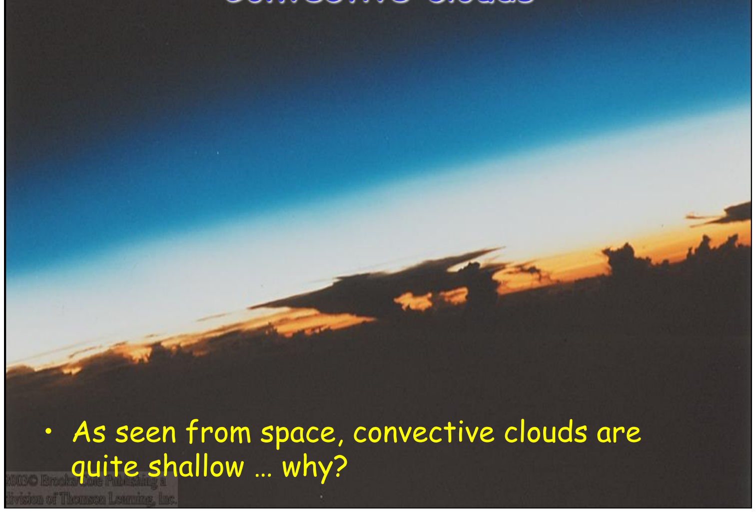


Figure 7.18



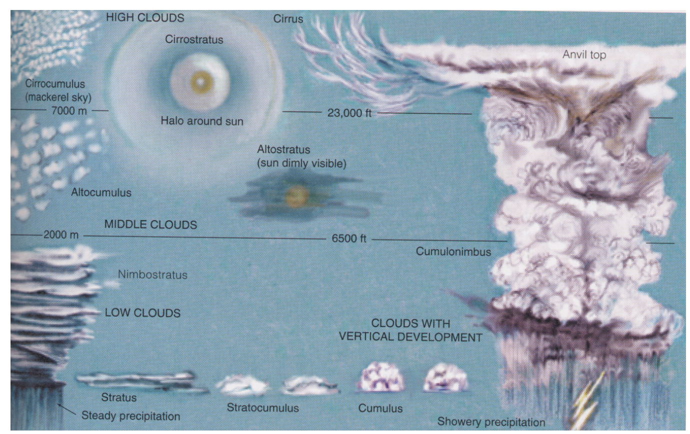
Cirrus

Convective clouds



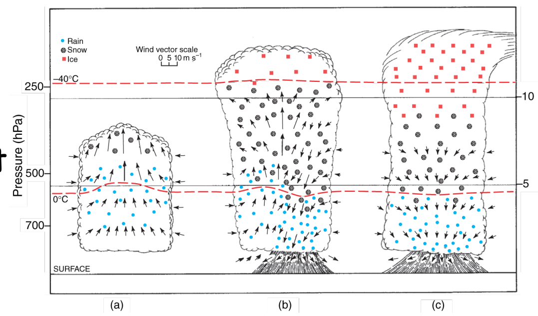
- As seen from space, convective clouds are quite shallow … why?

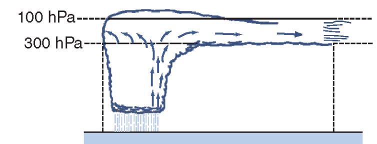
Cloud type summary



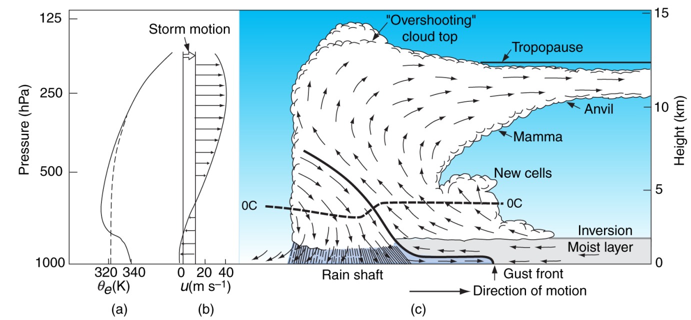
Lifecycle of a Simple Thunderstorm

- Updraft
- Glaciation
- Rain shaft
- Anvil
- Collapse
- Cirrus "debris"



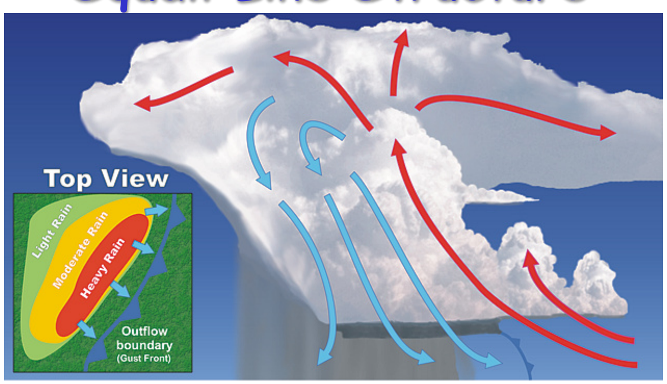


Organized Squall Line



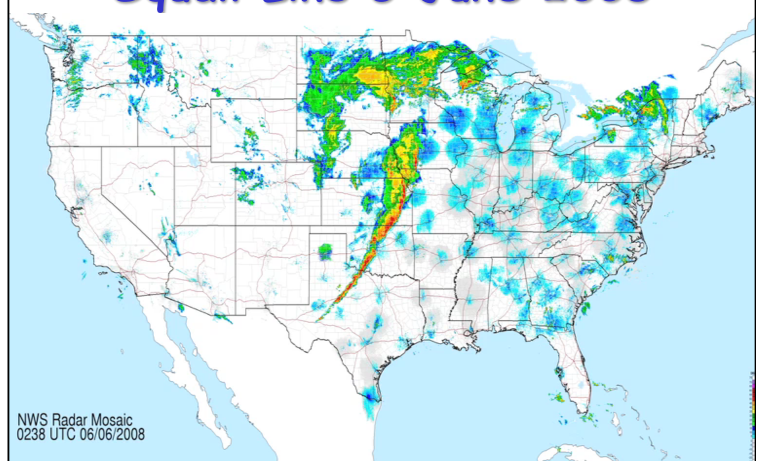
- Decoupling of updraft and downdraft due to "shear" (vertical change in horizontal wind)
- Propagation by initiation of new convective cells along gust front at leading edge of cold pool

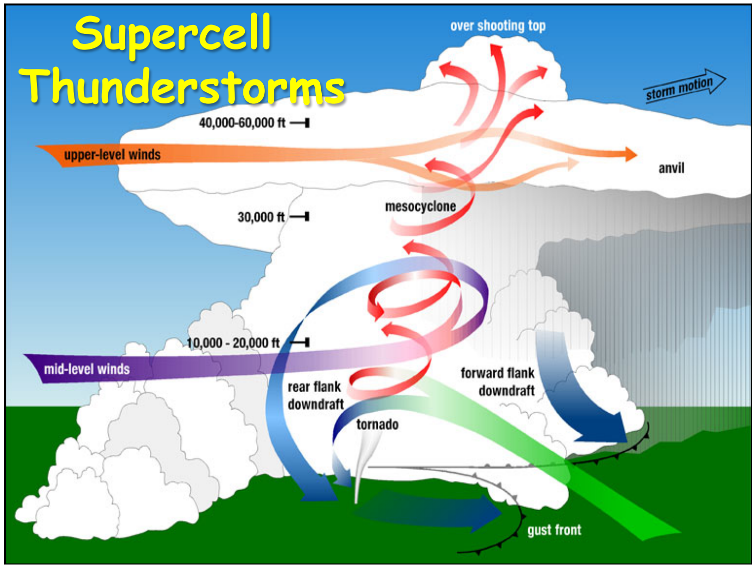
Squall Line Structure



Sequence at surface: (1) strong wind gust under rain-free cloud; (2) heavy rain; (3) tailing off to light rain

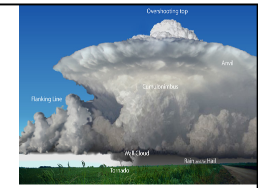
Squall Line 5 June 2008





Supercell Thunderstorms

- Highly-organized single-cell storms persisting for hours, responsible for nearly all tornados and damaging hail
- Conditions:
  - Very unstable, moist environment
  - Winds turn clockwise with height (e.g., from south at surface, from west aloft)
- Characteristics:
  - Storm-scale rotation
  - Huge updrafts to 100 mph
  - Wall clouds, tornados, violent downdrafts and surface gusts



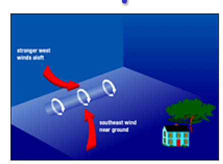


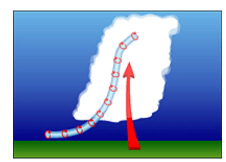

Tornados

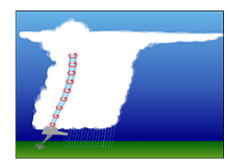
- Small but intense surface vortices produced by supercell storms
- Surface winds can be > 250 mph
- Average of 1000 reported per year in USA, with 80 killed and 1500 injured

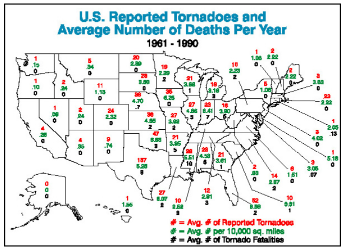
How Tornados Form:

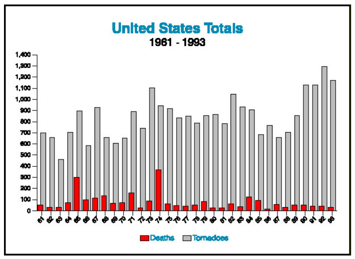
pre-existing vorticity is tilted and then stretched in a supercell thunderstorm updraft


Surface friction produces "roll vortices"


Vortex is entrained into updraft and tilted into vertical


Vortex tube is stretched in rotating updraft and intensifies





US Tornado Occurrence

- Roughly 1000 tornados each year in US
- Many more in US than anywhere else in the world!
- Trends in reporting, but probably not trends in actual occurrence

"Tornado Alley"