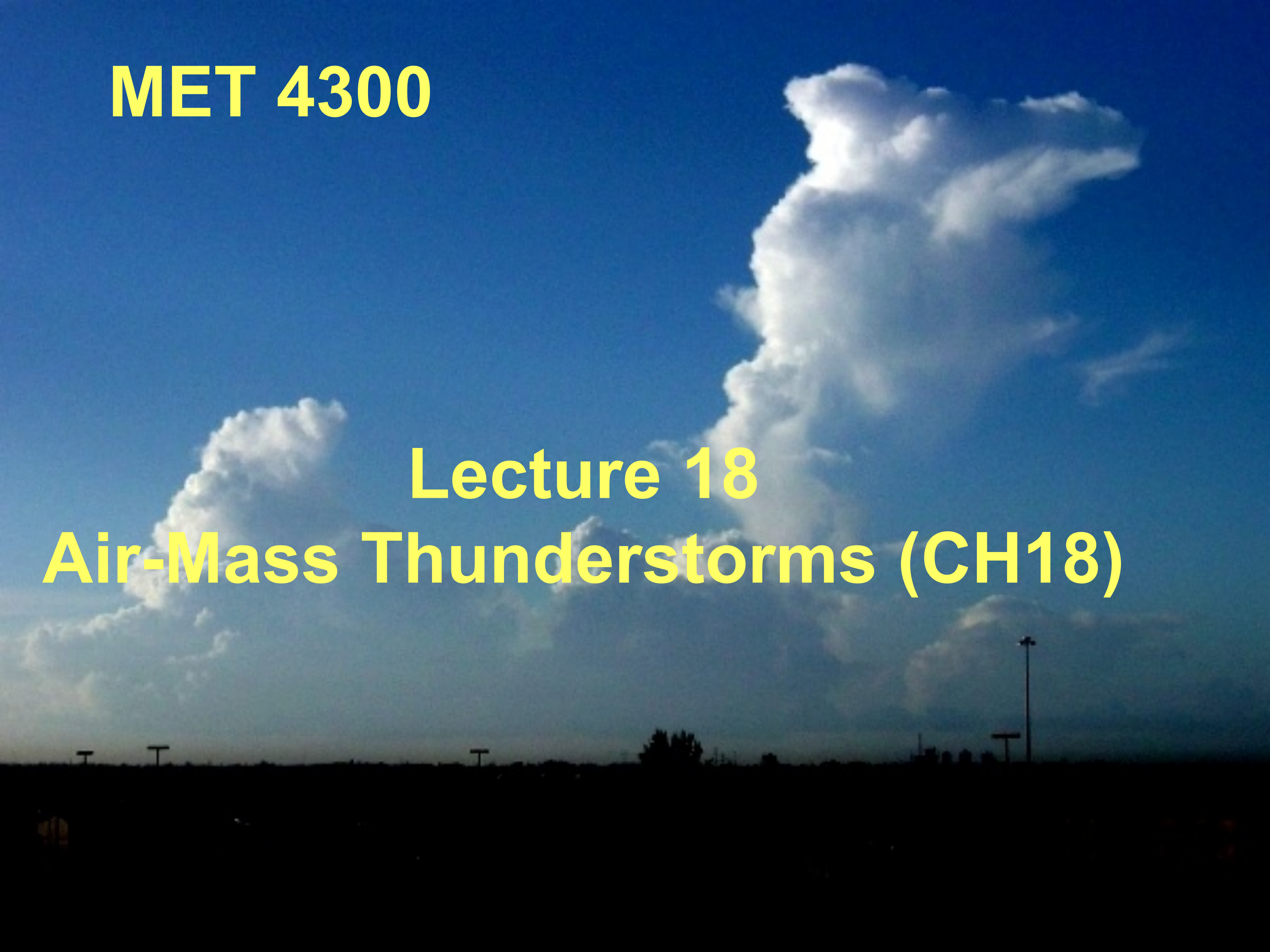


MET 4300

Lecture 18
Air-Mass Thunderstorms (CH18)

Thunderstorms

- Also called cumulonimbus clouds. Thunderstorms are tall vertically developing clouds that produce lightning and thunder.
- Most are not severe.
- NWS's severe thunderstorm definition:

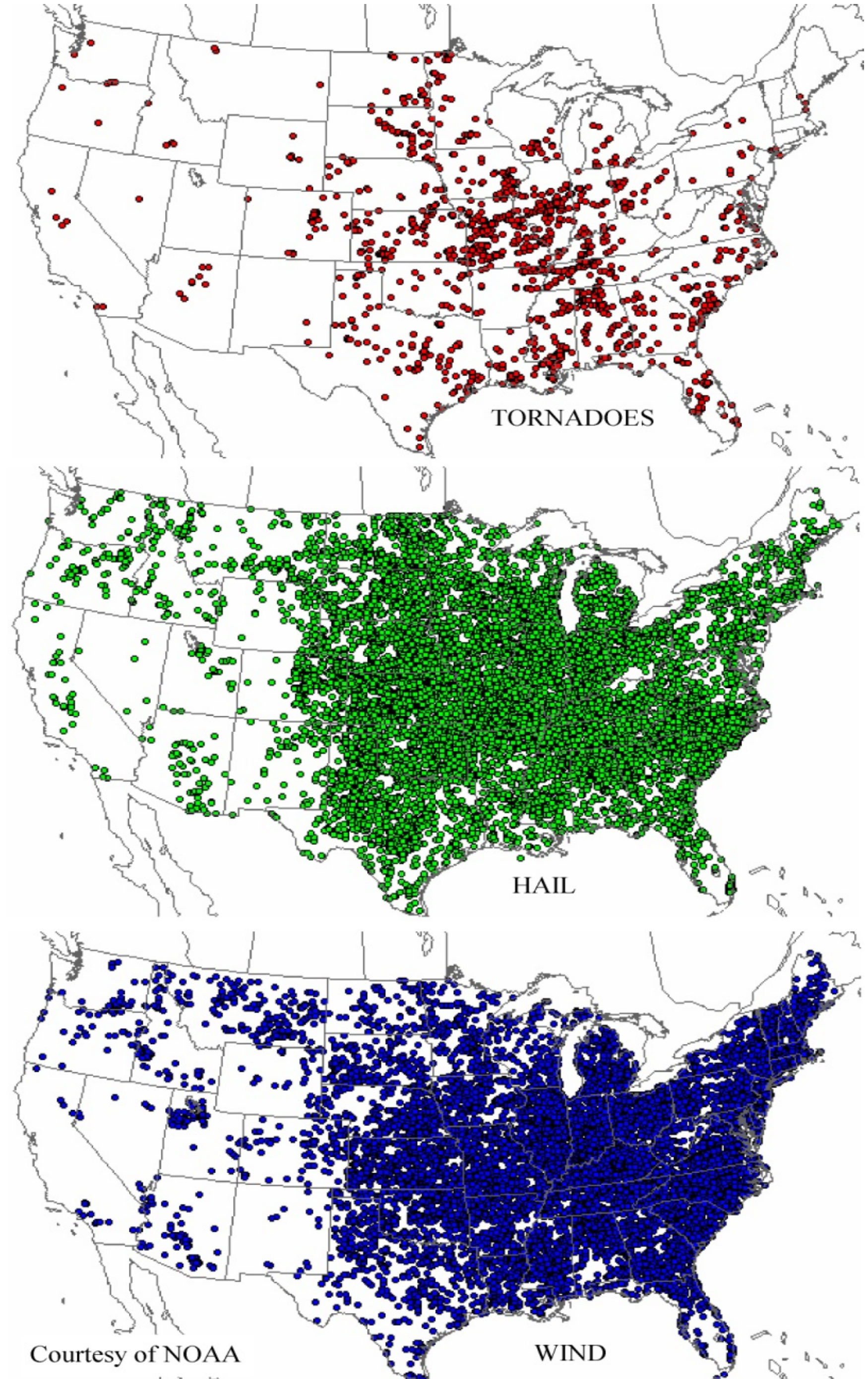
  1) large hail (diameter>= 1 inch; was ¾ inch before Jan 2010)

  2) wind >= 50 kt

  3) a tornado
- Lightning occurs in all thunderstorms, so it is not used a criterion for sever thunderstorm/ weather.

Locations of Severe Weather Events in 2009

- Damage from severe thunderstorms (lightning, hail, severe winds, tornadoes): $2.4 billion in US over 2000-2009. 116 fatalities and 1395 injuries annually.



Four Factors for the Formation of Severe Thunderstorms

- **1. A source of moisture**
- **2. A conditionally unstable atmosphere**
- 3. A mechanism to trigger the **updraft**, either through lifting or heating of the surface
- 4. **Vertical wind shear**
- Large conditional instability and strong vertical wind shear favor destructive thunderstorms

Courtesy of Bruce Lee

Types of Thunderstorms

- **Airmass (ordinary) thunderstorms**: single isolated thunderstorm that forms in absence of vertical wind shear
- **Frontal squall lines**: a very long line of thunderstorms developing along frontal boundaries during the cool season.
- **Mesoscale Convetive Systems (MCS):** develop along subtle boundaries (differential heating of air over surfaces with different properties) in warm season, self-organized, in a scale of a few km to several hundred km
- **Supercell thunderstorms:** violent storms developing if winds increase rapidly with height ahead of a strong front or a less distinct boundary. Very strong, rotating cells that produce most violent weather and the majority of large tornadoes. Can occur in both warm and cool season.

Four lectures for CH18

- Airmass thunderstorms (Today lec 22)
- Mesoscale Convective Systems (MCS, Thursday Lec. 23):
- Frontal squall lines: Next week Lec. 24
- Supercell thunderstorms: next week, Lec.25

Airmass Thunderstorms (TR)

- **Airmass TR** occur well within an airmass rather than along a front.
- **All convection requires:**
  - **Conditional instability**
  - **Lift or heating**
  - **Moisture**
- **Airmass TR have**
  - **One updraft <10 m s^{-1}**
  - **A few km across**
  - **Extends through the depth of the troposphere**
  - **Low shear**
  - **Moderate instability CAPE < 1000**
  - **A well defined life cycle: 1 h**
  - **Isolated single cells**
  - **Move nearly with the surrounding wind**

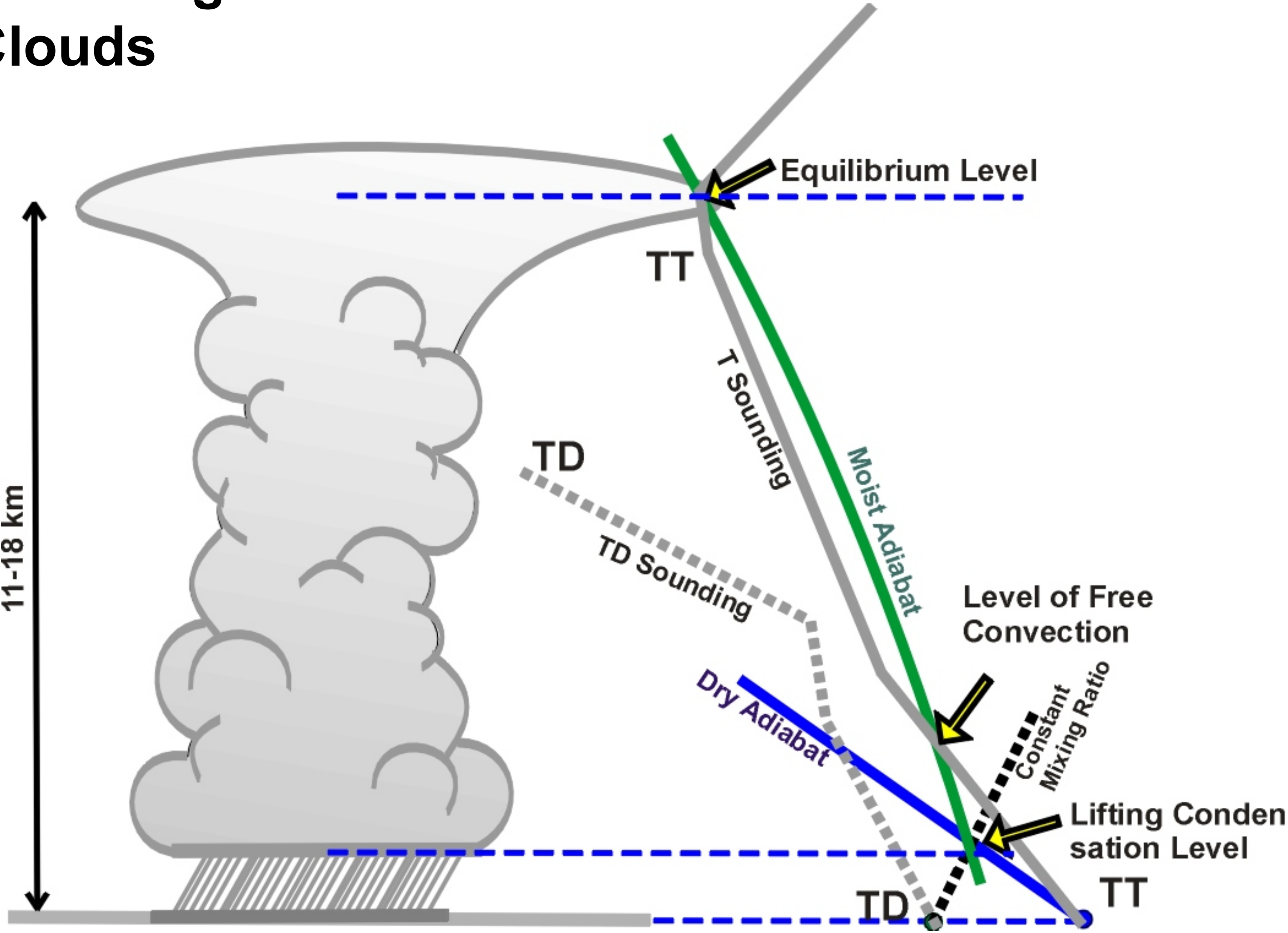
Courtesy of Alan Moller

Airmass Thunderstorms

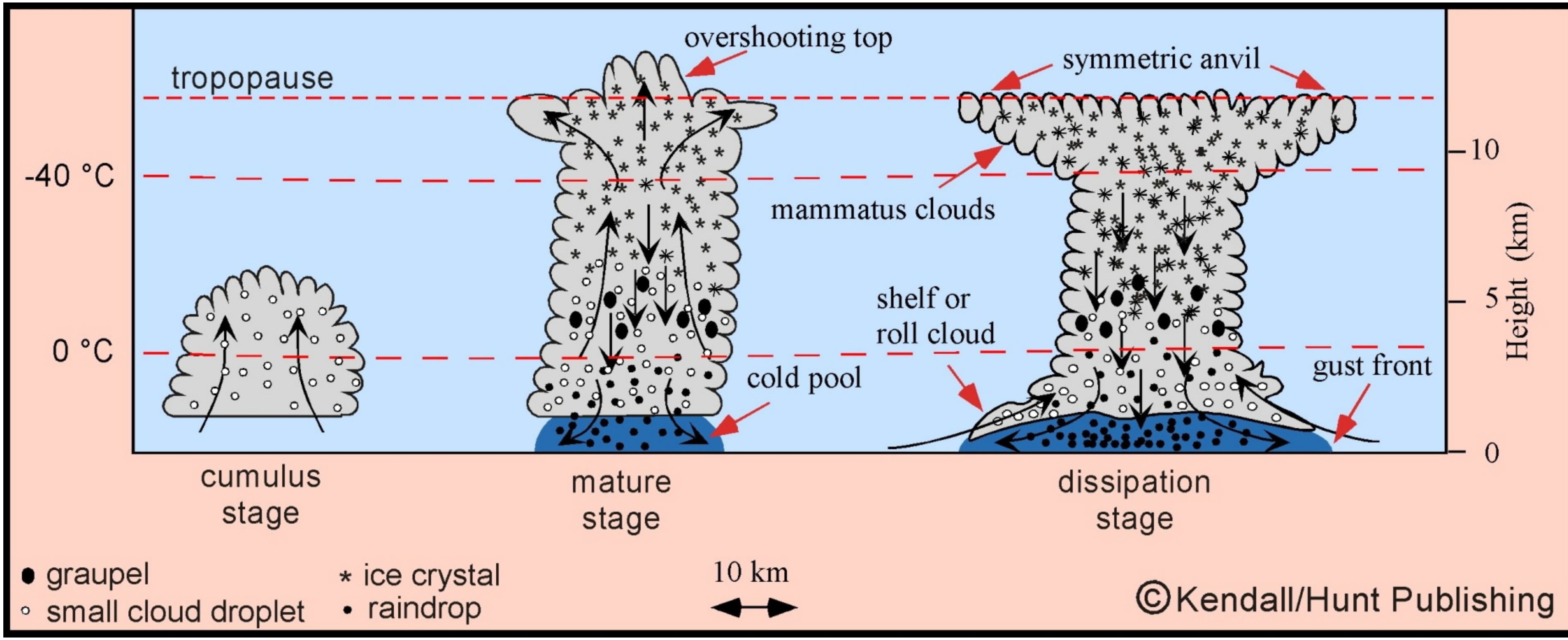
- Often form along weak boundaries, and can be triggered by surface heating or lifting along mountain
- Airmass TRs are found far from frontal boundaries (where wind shear is strong)
- Precipitation size could cover 15-20 km in late stage
- In absence of wind shear, they grow vertically without any significant tilt

Courtesy of Alan Moller

Soundings and the Structure of Convective Clouds

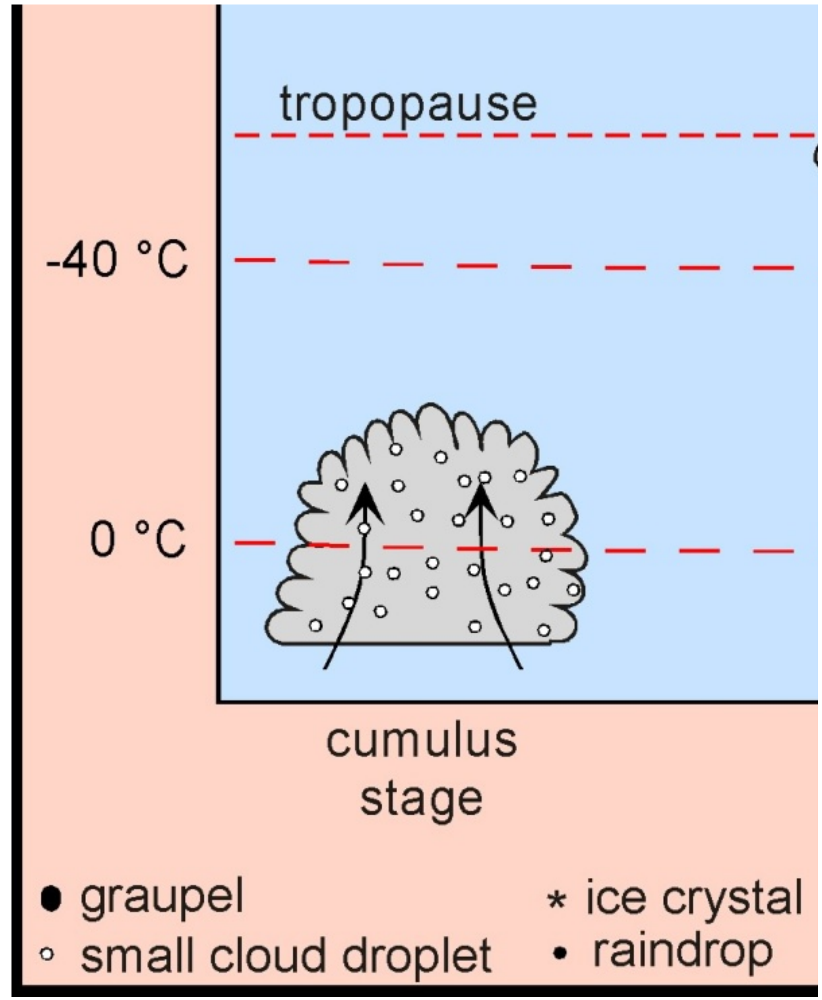


Life Cycle of Airmass Thunderstorms



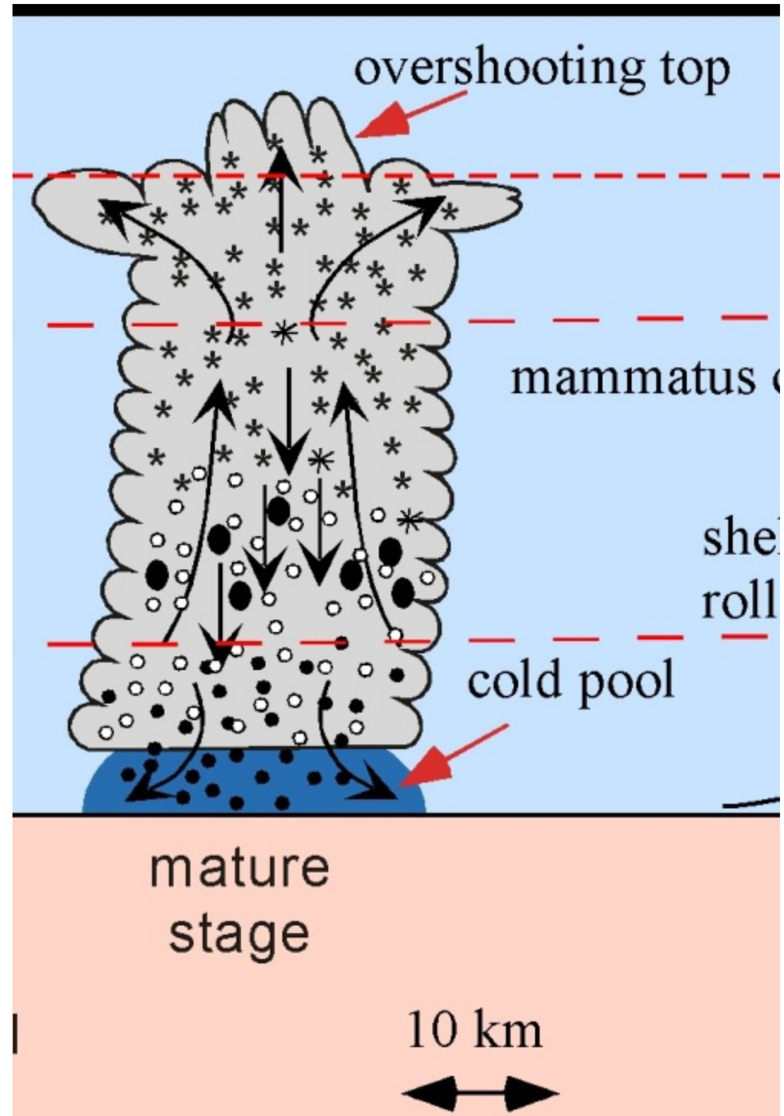
Cumulus Stage

- Clouds consist of a warm buoyant plume of rising air– updraft
- The updraft velocity increases rapidly with height.
- Clouds are composed primarily of small liquid cloud droplets, with little or no raindrops or ice crystals
- Ice crystals begin to form when clouds reach -10^{o}C to -20 ^{o}C.
- Eventually these particles grow large enough to precipitate.



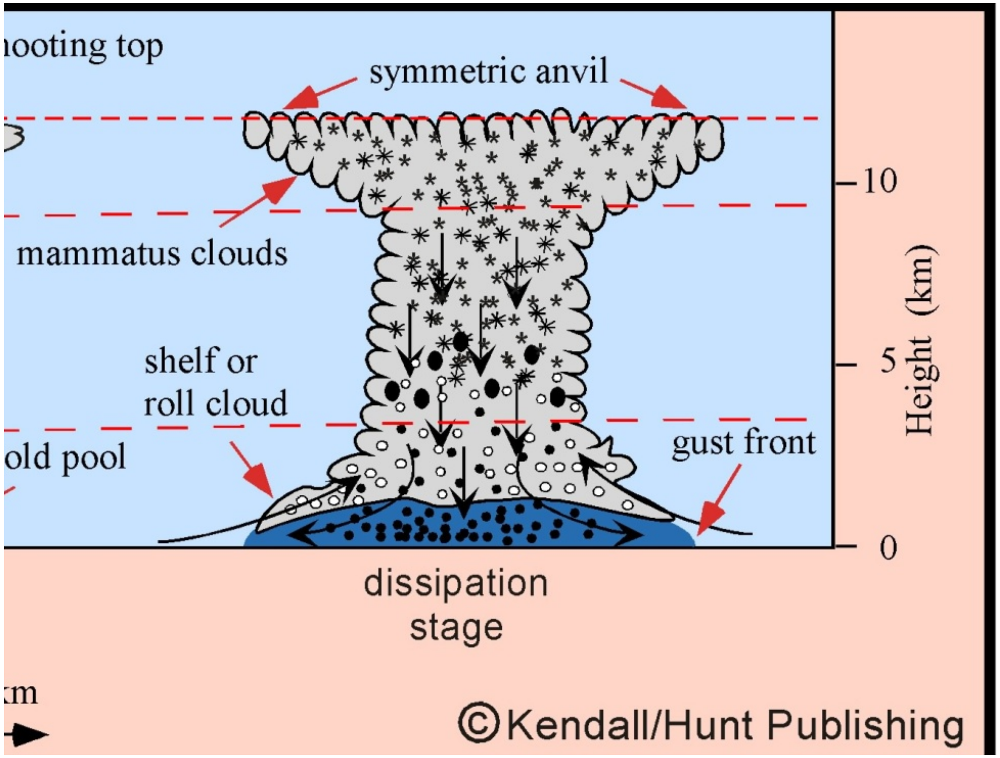
Mature Stage

- As the clouds reach the tropopause, it's in mature stage
- Strong stability of the stratosphere quickly inhibits further ascent
- **Updraft** in most TRs are strong enough that the clouds will extend a short distance into the stratosphere, producing a bulge at the cloud top, calling an **overshooting top**
- **Downdraft** created by **precipitation**, enhanced by evaporation cooling due to **entrainment.**
- A **cold pool** forms near surface by the accumulated rain-cooled air.
- Downdraft counteracts updraft.



Dissipation Stage

- At this stage, downdrafts completely shut off the updrafts, the storm is composed of downdrafts only.
- Heavy rain and rain-cooled air descend from the storm base.
- Produce an **outflow** of cool air → **gust front.**
- New clouds will form over gust front as warm air lifted by cold pool→ **shelf clouds or roll clouds**.
- New cells may develop near the cold air's leading edge. May develop to MCSs.

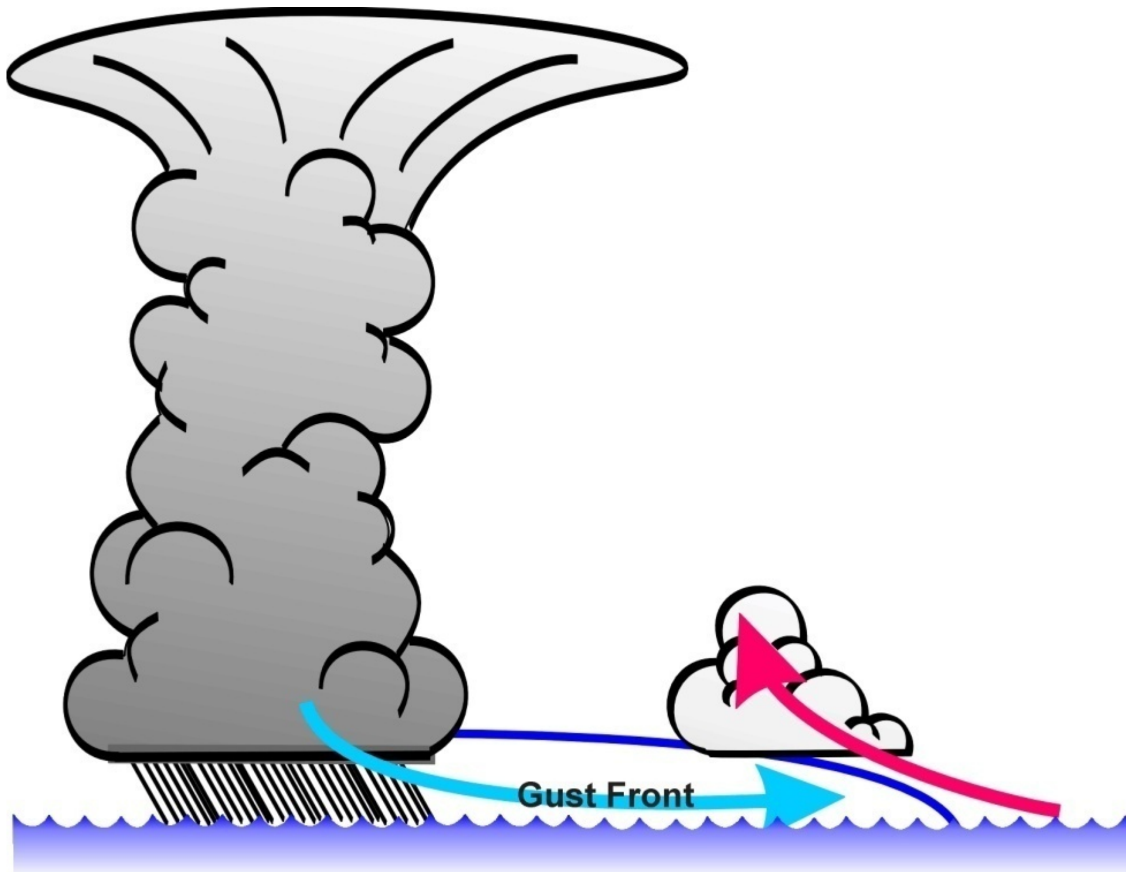


- Air from the updraft exhausts horizontally , forming an **anvil** (cirrostratus, altostratus, and cirrus). Anvil is symmetric with little shear, but asymmetric if under high shear.
- **Mammatus** clouds form at the base of anvils (bag like) due to descending of evaporation-cooled air.

A few Important Terms Associated with Thunderstorms

- **Overshooting top:** a bulge at the thunderstorm cloud top when the clouds extend a short distance into the stratosphere under strong updrafts.
- **Anvil**: Air from the updraft exhausts horizontally at the tropopause, forming a cloud feature called anvil. Anvil is symmetric when shear is little, but asymmetric when shear is strong. Cirrus farther from the storm, cirrostratus & altostratus closer to the storm.
- **Mamatus clouds** form at the base of anvils, rounded "bag" hanging from the anvil, forming as particles evaporate. Evaporationally cooled air descends downward.
- **Entrainment:** Precipitation encounters dry air mixing in from the side and the top of the cloud.

New cell formation

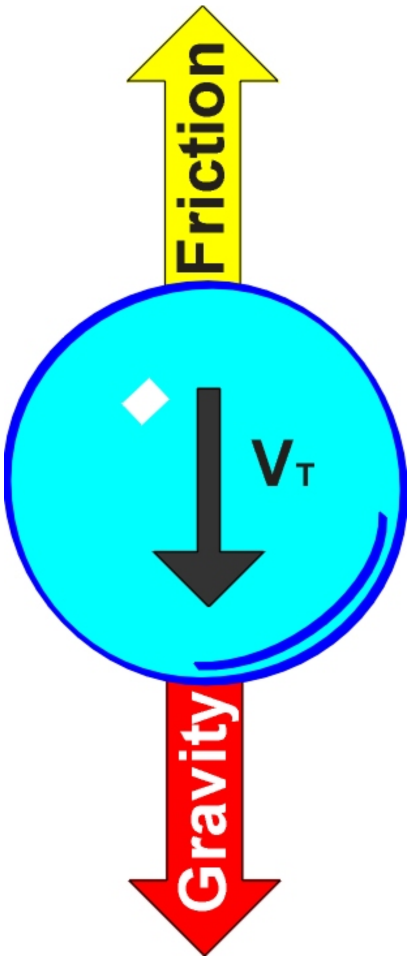


Kinds of Precipitation

- ***Rain***: Liquid water drops > 0.5 mm in diameter falling from the sky
- ***Drizzle***: Liquid water drops < 0.5 mm in diameter falling from the sky
- **Virga:** Like rain but evaporates before it reaches the ground.
  - Virga is a hydrometeor, but it isn't precipitation.
- ***Hail***: More or less spherical ice > 5 mm in diameter
- ***Graupel***: More or less spherical ice < 5 mm in diameter
- **Snow**: Ice crystal deposited directly from vapor, or aggregates (clumps) of crystals
- Note that the boundary between Hail and Graupel is 10 times larger than the boundary between Rain and Drizzle

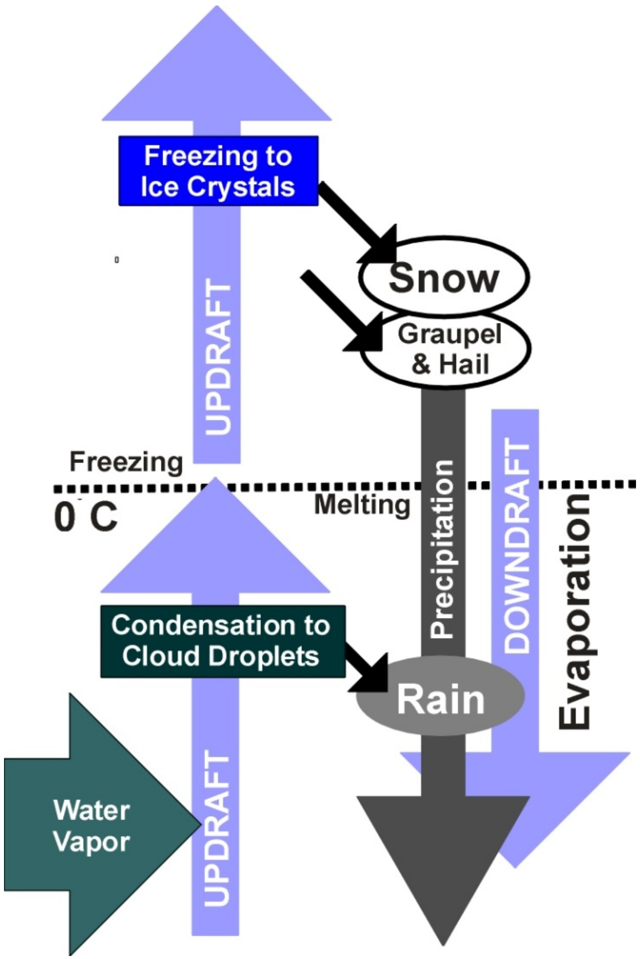
Terminal Velocity

- Hyrdometeors fall speed is a balance between friction and gravity.
  - Cloud particles: mm or cm s^{-1}
  - Rain up to 8 m s^{-1}
  - Snow 1-2 m s^{-1}
  - Hail > 10 m s^{-1}
- VT increases for
  - Lower air density
  - Larger hydrometeor size
  - Smoother hydrometeors



What Happens in a Cloud?

- Updraft leads to cooling and condensation.
- Forms cloud droplets, 10-50 µm in diameter.
- Cloud droplets collide and coalesce to form rain
- Are also carried upward to temperatures < 0^oC
- Many eventually freeze
- Ice grows faster than supercooled liquid H_2O
- Forms snow, graupel, and hail
- Which may melt to form rain if it falls below 0^oC level
- Precipitation loading and evaporative cooling force downdrafts.



What are clouds made of?

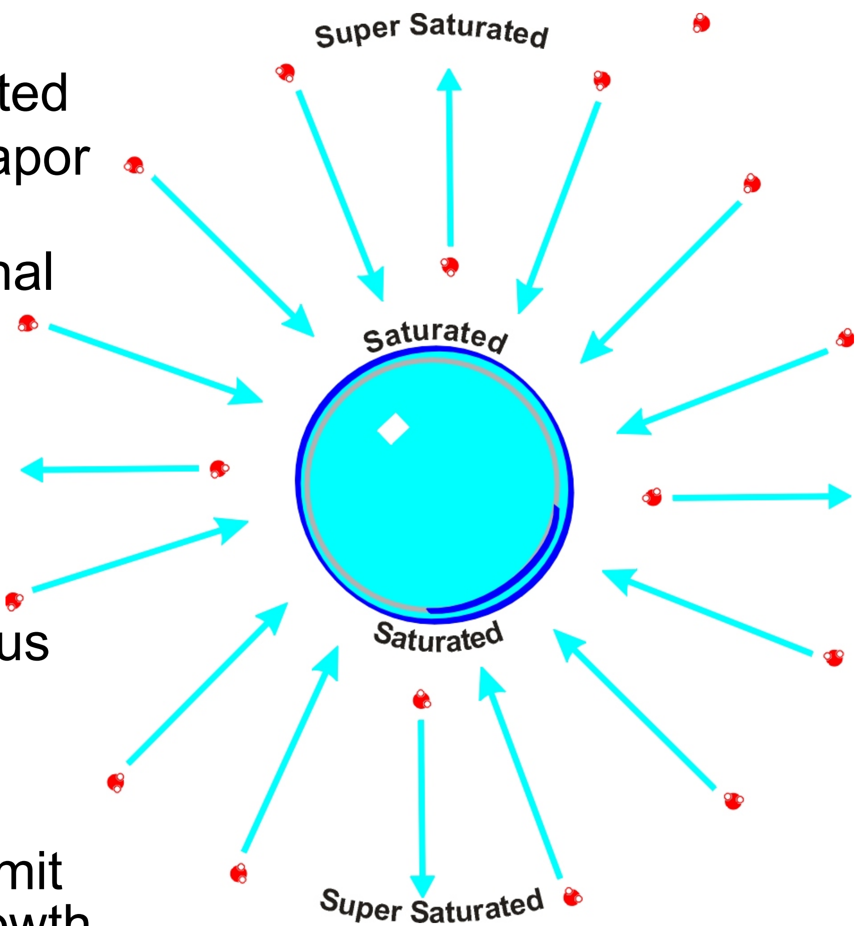
- **Not of raindrops,** but of **suspended cloud droplets**---about 100 times smaller than raindrops, i.e. 10-80 μm (0.01-0.08 mm) in diameter.
- Let’s start with cloud droplet formation in supersaturated air through **Condensation of water vapor**:
- **Homogeneous nucleation:** Water drops (or ice crystals) *might* form in pure air with nothing but dry air and H_2O involved.
- Each water molecule added has to do work against the surface tension.
- Thus, it is hard to make cloud droplets from scratch, because the amount of work per molecule is more when the droplet is smaller.
- Homogeneous nucleation requires **> 110% relative humidity** (or 10% supersaturation), which generally does not occur in the atmosphere.

Heterogeneous nucleation

- Water drops (or ice crystals) form from the vapor on some sort of **substrate** or by **soaking** into a salt particle.
- For wetable nuclei, water attaches to the surface.
- For hygroscopic (tending to absorb moisture from the air) nuclei, water soaks into the surface and may actually dissolve the nucleus.
- What makes a good ***Cloud Condensation Nucleus*** (CCN)?
  - Reasonably big (for example, an aerosol particle)
  - Easily wetable (0.1 μm) or soluble (0.01 **μ**m).
- Over land, 100-1000 CCN cm^{-3} typically become active at 1% supersaturation
- Over the oceans, <100 CCN cm^{-3} typically become active at 1% supersaturation

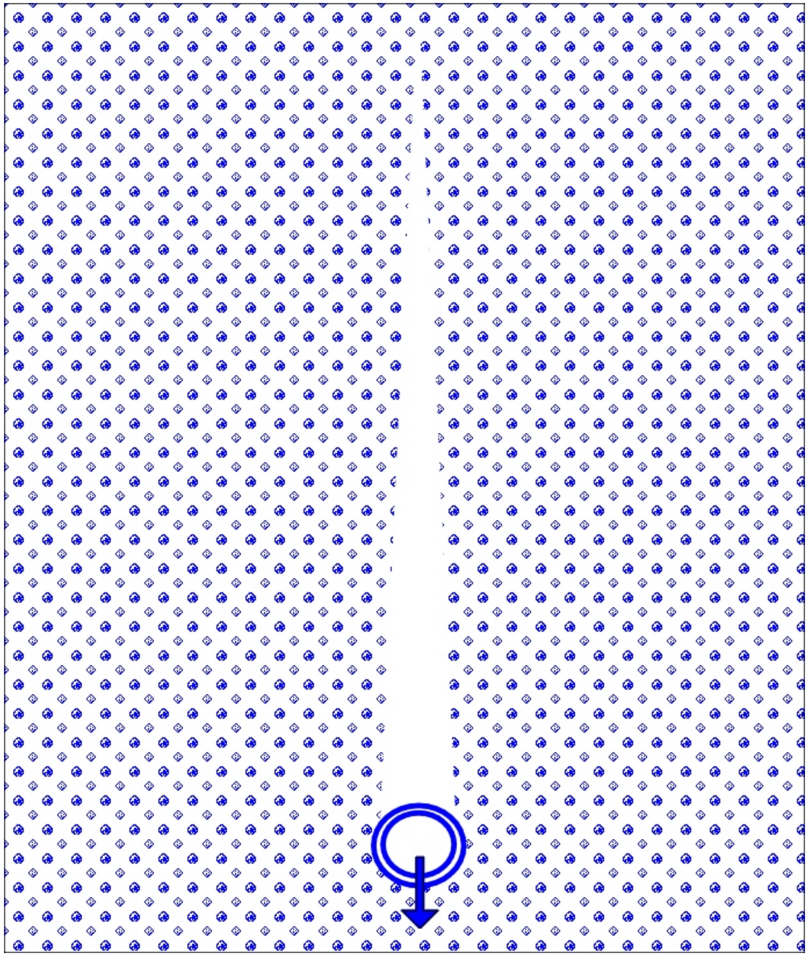
Growth of Cloud Droplets by Diffusion

- The cloud becomes super-saturated
- Water vapor diffuses from high vapor density to low vapor density
- Rate of mass growth is proportional
  - Droplet area
  - Supersaturation
- Rate of growth of radius
  - Area is proportional to radius squared
  - Volume is proportional to radius cubed
  - Radius growth is inversely proportional to radius itself.
  - Thus there is a well-defined limit of 10-80 μm for diffusional growth



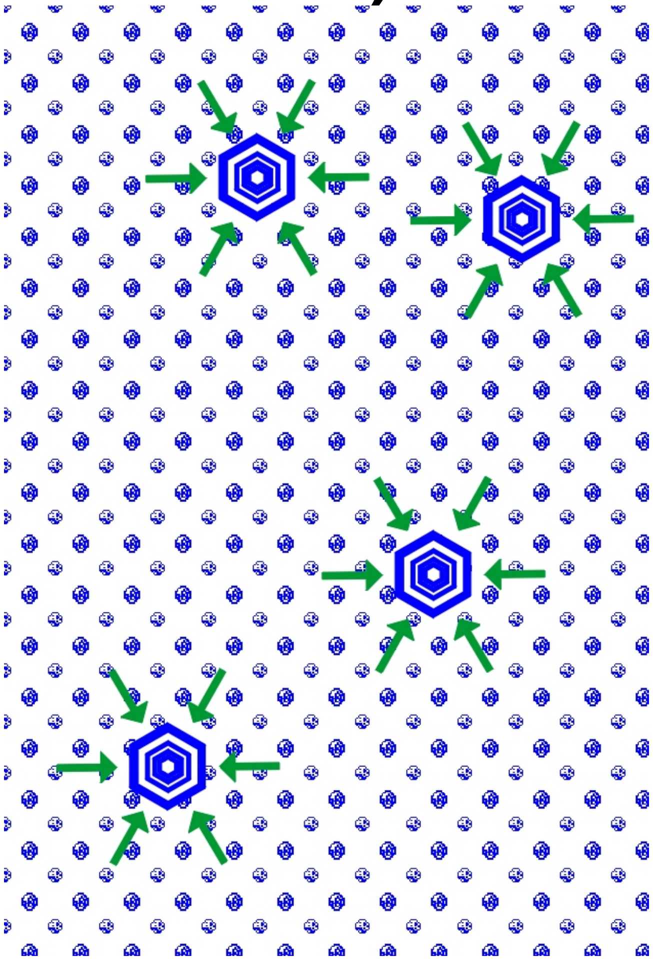
Growth of Warm Rain

- **Warm Rain:** Falls from clouds where T > $0^{o}C$ throughout
- **Autoconversion:** A few droplets collide randomly and merge, becoming larger than the others
- Hydrometeors fall near their terminal velocity
- Larger, denser or rounder hydrometeors fall faster
- In clouds warmer than $0^{o}C$, precipitation forms when larger particles sweep up smaller ones as they fall through the cloud.
- Called ***Collision Coalescence***.

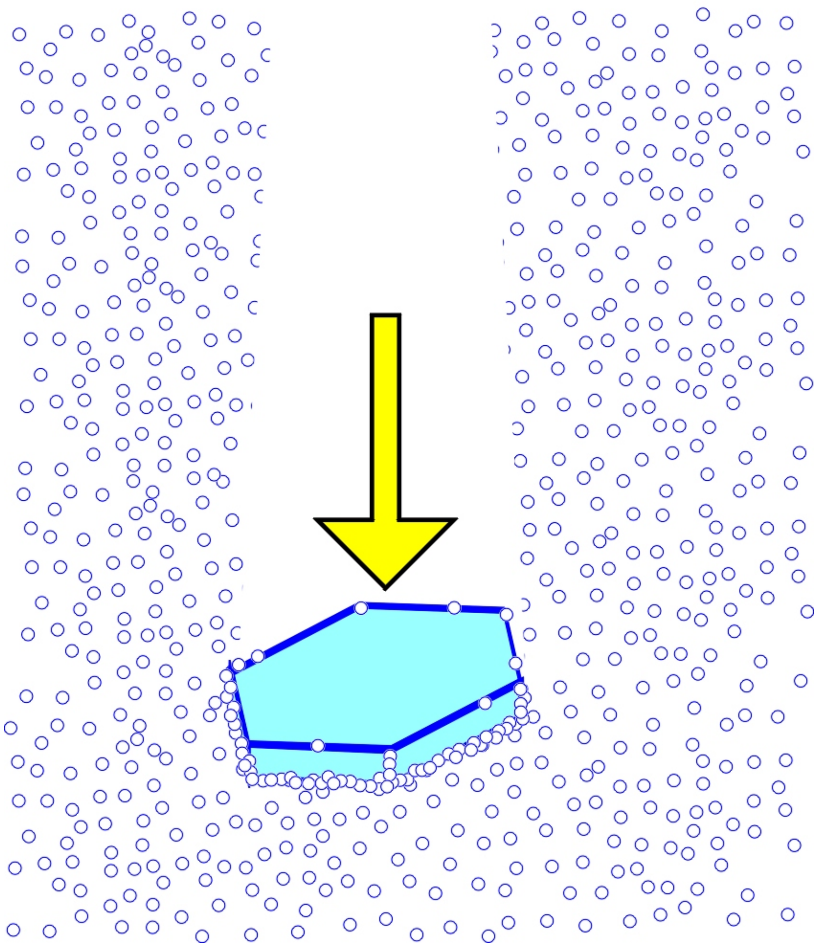


Mixed-Phase Clouds, T<0°C (Cold Rain Process)

- Both freezing and condensation generally require nuclei to start the process
- Natural clouds have plenty of condensation nuclei (100,000/liter) but few freezing nuclei (10-100/liter)
- Consequently many clouds colder than 0°C contain ***Supercooled*** liquid H_20 that has not yet frozen.
- May be as cold as -20°C
- When some ice does form,
  - the ice crystals grow
  - at the expense of supercooled water droplets
  - Bergeron-Findeisen process (cold rain process: a process of ice crystal growth that occurs in mixed phase clouds (containing a mixture of supercooled water and ice))
- Artificial freezing nuclei can promote growth of snow that melts to form rain



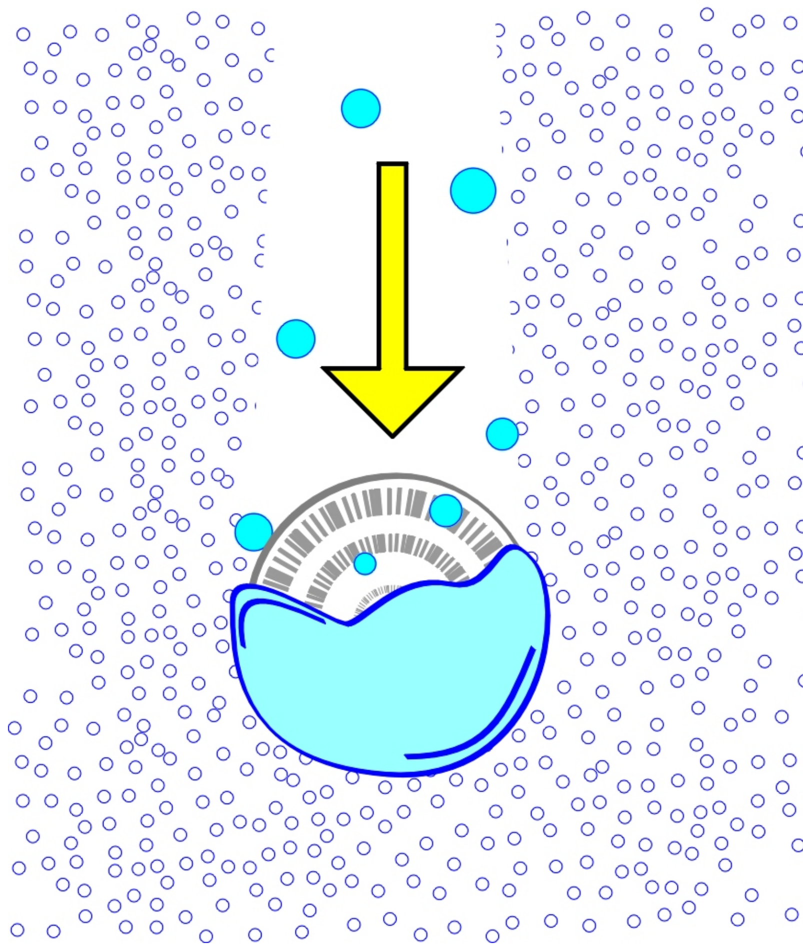
Riming (Graupel)



- Starts with a vapor-grown ice crystal
- Falling through a supercooled cloud
- Droplets freeze on leading edges.
- Forming spongy ice
- This is how graupel forms.

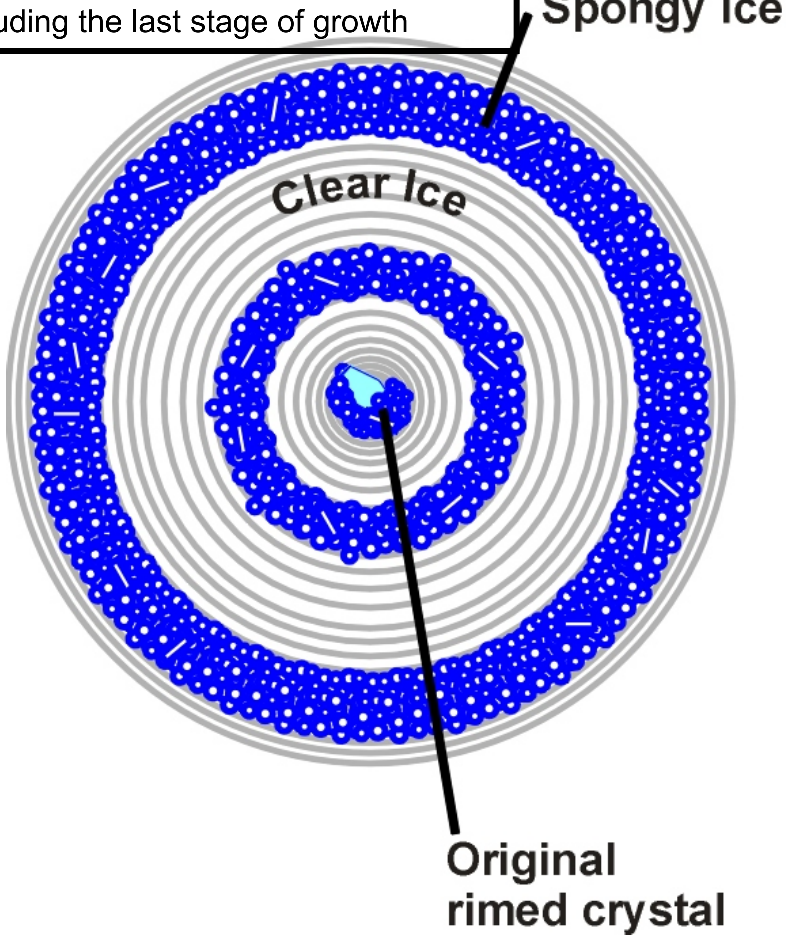
Wet Growth or Wet Riming (Hailstone)

- Temperatures > -5°C
- Latent heat released by freezing keeps hailstone at 0°C.
- Coated with liquid water
  - Some freezes
  - Some is shed as drops at 0°C



Structure of Hailstones

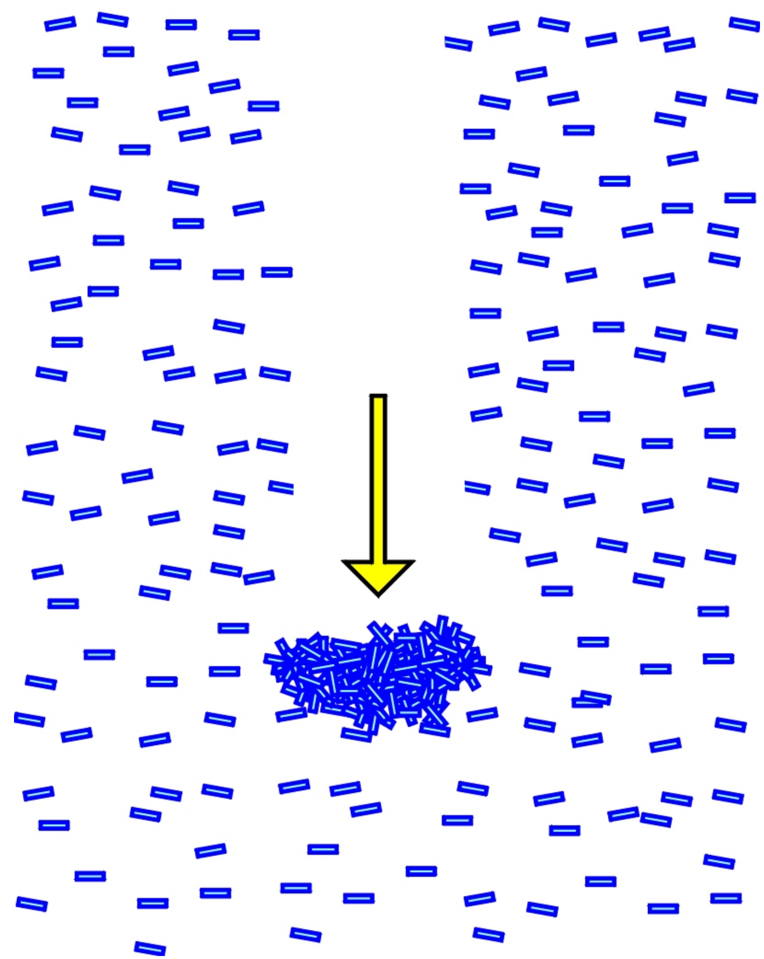
Spongy ice produced by:
Two episodes of “dry” riming plus initial growth
Clear ice produced by:
Three episodes of wet riming including the last stage of growth



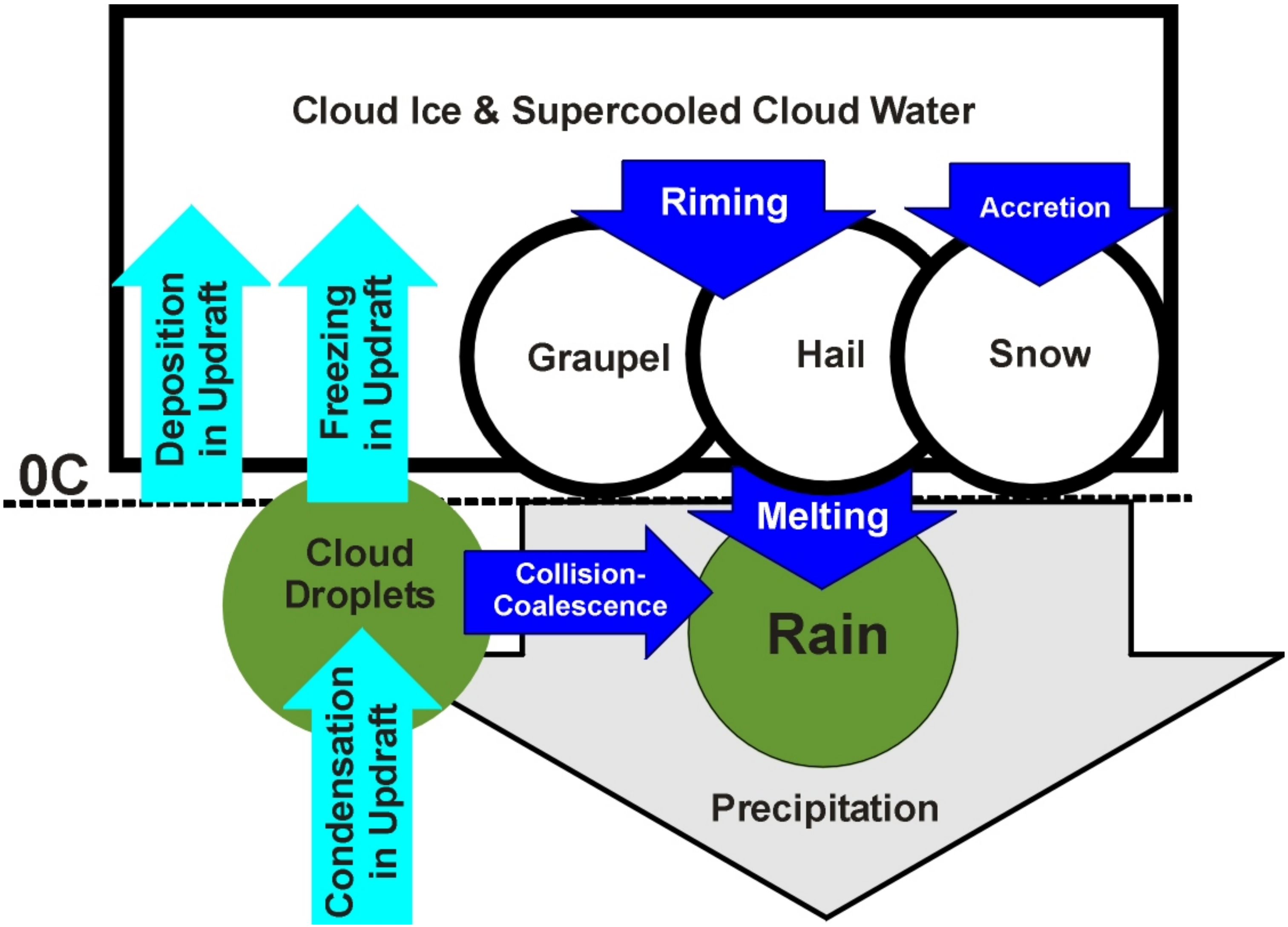
- Updrafts in Cb’s are often stronger than hydrometeor terminal velocities.
- Leads to recycling of graupel and hail
- Forming multiple layers of clear (wet riming) and spongy ice (dry riming)
- In very strong updrafts hailstones can get really big---
- Coffeyville KS, 22JUN03
  - 18 cm diameter,
  - 750 gm

Aggregation (Snow)

- Falling frozen hydrometeor collects other frozen hydrometeors
- Most snowflakes are aggregates of vapor-grown crystals
- Works best at temperatures > $-5^{o}C$
- Big, soggy flakes vs. diamond dust



Precipitation Formation



Summary

- Review cloud geometry in relation to LCL, LFC & EL
- Air Mass Thunderstorms require low shear and moderate instability
- Life cycle
  - Cumulus---all updraft, no ice of precipitation
  - Mature---Mixed up & downdrafts, some ice and precipitation
  - Dissipating---Predominantly downdrafts, glaciated precipitating hard
- Precipitation:
  - Drizzle---liquid < 0.5 mm diameter
  - Rain---liquid > 0.5 mm diameter
  - Graupel---ice < 5 mm diameter
  - Ice---Ice . 5 mm diameter
  - Snow---ice crystals
- Terminal velocity---balance between gravity & friction
- Hydrometeor growth by diffusion is limited to 10-80 μm
- Warm rain grows by autoconversion and collision coalescence
- Cold rain (Bergeron-Findeisen) process---Ice scavenges vapor from supercooled liquid
- Hail and graupel grow by (wet & dry) riming; snow flakes grow by aggregation
- In strong updrafts hail can recycle, becoming layered