Formation of precipitation

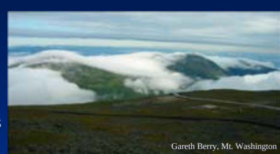
- Mechanisms for hydrometeor growth
  - Warm cloud processes
    - Condensation
    - Collision-coalescence
  - Cold cloud processes
    - Vapor deposition (Bergeron-Findeisen process)
    - Riming/accretion
    - Aggregation

How mother nature creates precipitation

- Step 1: Cloud droplet formation and growth
  - Condensation
  - "Collision-coalescence"
- Step 2: Glaciation
- Step 3: Vapor deposition (a.k.a., diffusional growth)
- Step 4: Accretion (riming)
- Step 5: Aggregation

Step 1: Cloud droplet formation and growth

- Clouds can form when the air becomes supersaturated (RH>100% for water or ice)
- May occur due to ascent
  - Air rises, expands, and cools
- Can also occur due to
  - Radiational cooling
  - Air moving over a cold surface
  - Mixing (e.g., contrails)

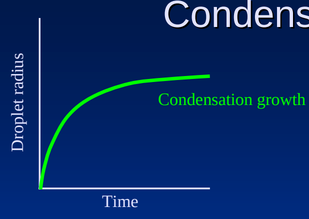


Clouds produced over Mt. Washington by orographic ascent

Cloud droplet formation and growth

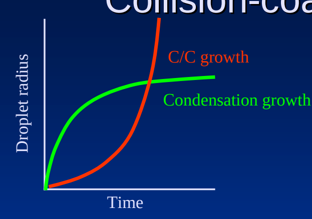
- Problem: Cloud droplets need help to form and grow
  - *Cloud condensation nuclei (CCN)* – Tiny particles (aerosols) that assist in the early stages of cloud droplet formation and growth
  - There are about 10 times more CCN in continental than maritime air masses
  - Thus, maritime clouds typically have fewer but bigger cloud droplets
    - More effective for riming

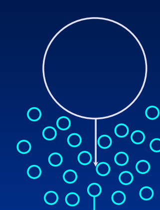
Condensation



- Droplet growth by condensation is initially rapid, but diminishes with time
- Condensational growth too slow to produce large raindrops

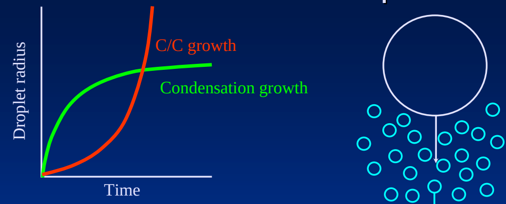
Collision-coalescence





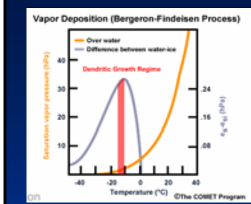
- Growth of small droplets into raindrops is achieved by *collision-coalescence*
- Fall velocity of droplet increases with size
- Larger particles sweep out smaller cloud droplets and grow

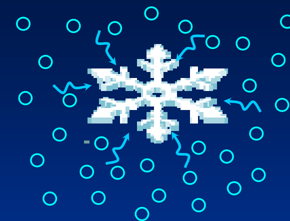
The warm cloud rain process



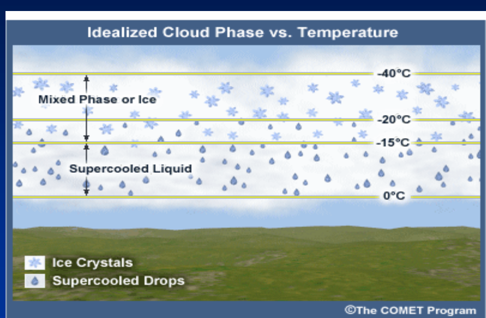
- Cloud droplet growth initially dominated by condensation
- Growth into raindrops dominated by collision-coalescence
- Most effective in maritime clouds

Vapor deposition (Bergeron-Findeisen Process)





- Saturation vapor pressure for ice is lower than that for water
- Air is near saturation for water, but is supersaturated for ice
- Ice crystals/snowflakes grow by vapor deposition
- Cloud droplets may lose mass to evaporation



Glaciation

- *Glaciation* – Conversion from liquid to mixed-phase (water and ice) cloud- Gotta happen for snow
- But! Water doesn't freeze at 32°F/0°C
  - *Supercooled cloud droplets* – exist at temperatures below 0°C
  - They need an ice nucleus to freeze
  - Number of ice nuclei is low when you are just below freezing
  - Clouds with "warm" cloud tops
    - May have a difficult time glaciating- may rime instead of snow
  - Need cold cloud tops, or "ice multiplication" for cloud to glaciate

Vapor deposition (Bergeron-Findeisen Process)


Sector plate

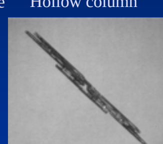

Stellar dendrite


Dendritic sector plate

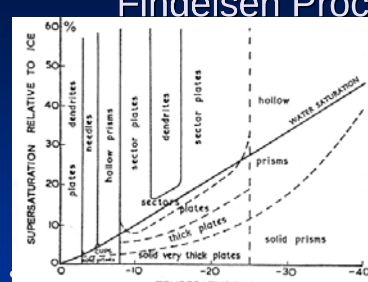

Hollow column

Snowcrystals.net

- *Habits* – types of ice crystal shapes created by vapor deposition)


Needle

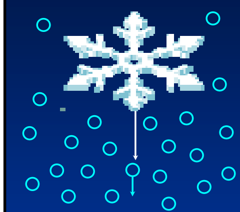
Vapor deposition (Bergeron-Findeisen Process)



Snowcrystals.net

– Temperature
– Supersaturation relative to ice

Accretion (riming)



Graupel (UCLA)

Hexagonal Lump Cone

Magono and Lee (1966)

- Growth of a hydrometeor by collision with supercooled cloud drops that freeze on contact
- *Graupel* – Heavily rimed snow particles
  – 3 types: cone, hexagonal, lump

Riming

- Favored by
  – Warmer temperatures (more cloud liquid water, less ice)
  – Maritime clouds (fewer, but bigger, cloud droplets)
  – Strong vertical motion (larger cloud droplets lofted, less time for droplet cooling and ice nuclei activation)

Accretion (riming)

Rimed Plate

Rimed Dendrite

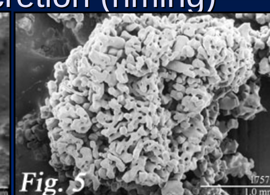
Graupel

USDA Beltsville Agricultural Research Center

"Riming is not good for skiing"
- Jim Steenburgh

Step 4: Accretion (riming)

Rimed Dendrite



Graupel

– Warmer temperatures (more cloud liquid water, less ice)
– Maritime clouds (fewer, but bigger, cloud droplets)
– Strong ascent (larger cloud droplets lofted, less time for droplet cooling and ice nuclei activation)

Aggregation

- Ice particles colliding and adhering with each other
- Can occur if their fall speeds are different
- Adhering is a function of crystal type and temperature
  – Dendrites tend to adhere because they become entwined
  – Plates and columns tend to rebound
  – Crystal surfaces become stickier above –5°C

The cold cloud precipitation process

- Condensational growth of cloud droplets
- Some accretional growth of cloud droplets
- Development of mixed phase cloud as ice nuclei are activated and ice multiplication process occurs
- Crystal growth through Bergeron-Findeisen process
  – Creates pristine ice crystals
  – Most effective at –10 to –15 C

The cold cloud precipitation process

- Other possible effects
  - Accretion of supercooled cloud droplets onto falling ice crystals or snowflakes
    - Snowflakes will be less pristine or evolve into graupel
    - Favored by:
      - Warm temperatures (more cloud liquid water)
      - Maritime clouds (bigger cloud droplets)
      - Strong vertical motion
  - Aggregation
    - Entwining or sticking of ice crystals

Resulting solid precipitation types (International Commission on Snow and Ice)

Plates
Stellar crystals
Columns
Needles
Spatial dendrites
Capped columns
Irregular particles
Graupel
Sleet Refreezing of melted snow
Hail "Big-time" riming

Depositional Growth

Riming

Summary

- Precipitation is not produced solely by condensation
- A cloud condensation nuclei is needed to initially help cloud droplets grow
- Collision-coalescence is needed for cloud droplets to grow into rain if cloud >0°C
- In mixed phase clouds
  - Mix of ice crystals and supercooled liquid water
  - Ice crystals form when cloud droplets are activated by an ice nuclei or through ice multiplication
  - Ice crystals grow "at expense" of cloud drops (Bergeron-Findeisen)
  - Accretion can increase the density of falling snow and SWE at ground
  - Aggregation can further increase hydrometeor size
- Most mid-latitude, continental rain is produced by mixed-phase clouds and involve ice-phase processes