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)

Cloud droplet formation and growth

- Problem: Cloud droplets need help to form and grow
  - Cloud condensation nuclei (CCN) — Tiny particles (aerosol) 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)

- Habit type is a function of
  - Temperature
  - Supersaturation relative to ice

Habits – types of ice crystal shapes created by vapor deposition

- Sector plate
- Stellar dendrite
- Dendritic sector plate
- Hollow column
- Needle

Snowcrystals.net

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Mainly ice

Mainly water
Accretion (riming)

- 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)

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
- Deposit 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