Lesson 7: Precipitation

Objectives:
- How does precipitation form?
  - How do cloud droplets form? Ice crystals?
  - What is the collision-coalescence process? The Bergeron process?
- What is the vertical structure of temperature during:
  - Snow
  - Sleet
  - Freezing rain
  - Rain
- How do we measure precipitation remotely

Recall from Lesson 5: Cloud Formation

- Need moisture & saturated air
- "Homogeneous nucleation"
  - Condensation of H₂O vapor to liquid without presence of Cloud Condensation Nuclei (CCN)
  - Lots of energy required to cross the Gibbs Free Energy barrier
    - Difficult for H₂O vapor molecules randomly moving around to bump together and stick together
    - Need high "supersaturation": RH not only > 100%, but RH > 115%
- "Heterogeneous nucleation"
  - Condensation of H₂O vapor onto a particle
    - Can occur at RH<100%
    - If particle is "hygroscopic" (has a positive affinity for water)
    - Typically occurs with RH between 100.5% and 102%
    - Called the "Solute Effect": the CCN (for example, salt, NaCl) chemically combines with H₂O and reduces the likelihood the newly-condensed H₂O will evaporate back to vapor.

Supersaturation

- Liquid water is unique molecule
  - Spherical liquid cloud droplet
    - Needs RH > 100% to maintain equilibrium (and not evaporate back to vapor)
  - Smaller the cloud droplet, the higher the RH needed to maintain equilibrium
  - If more RH is present than required for equilibrium
    - Cloud droplet grows by condensation
From cloud droplets to precipitation....

• How long do you think it would take for rain to form from a cloud whose droplets are growing PURELY from condensation?

Condensation from aircraft: "contrails"

From cloud droplets to precipitation....

• If cloud droplets (diameter 20 µm) grew ONLY by condensation:
  – 72+ hours to grow into a raindrop (diameter 2000 µm, or 2 mm)
• So why can clouds form & produce rain in sometimes only 30 minutes?

Cloud over the Andes Mountains in Peru

Collision and Coalescence:
Explains how cloud droplets grow to rain drops

• Larger drops fall exponentially faster relative to smaller drops
• Grow by colliding and coalescing
  – Process is positive feedback: larger drops fall faster, collide & coalesce more, grow even larger, and fall even faster

Collision-Coalescence occurs in clouds with temperatures > -15°C!!

(yes, liquid water can, and often, exists in atmosphere even if temp is < 0°C; energy req’d to freeze a spherical, pure-liquid water droplet is very large, so liquid water commonly exists to -40°C)
Collision-coalescence process

- Also called “warm rain” process
- Cloud droplets and precipitation remain liquid
  1. \( H_2O \) condenses onto CCN
     - Forms cloud droplet
     - Growth initially by condensation
  2. Bumps into other cloud droplets
     - Grows by collision and coalescence
     - Different droplets are different sizes and move at different speeds (thus enabling col-l-coal process)
  3. Eventually becomes heavy enough to fall out of updraft
     - Continues growing by coll-coal process

What happens when air temperatures are below freezing?

- Again, water is a unique molecule
  - Ice has a lower saturation vapor pressure than liquid water
    - Thus ice crystals will grow at the expense of liquid water droplets
    - This is called the “Bergeron Process”

Small droplets have evaporated and redeposited onto the ice crystal – the Bergeron Process – because ice has lower saturation vapor pressure than water for the same temperature
More on ice crystal formation

- Similar to how CCN form cloud droplets, Ice Nuclei (IN) promote formation of ice crystals
- Two types of Ice Nuclei
  1. Deposition nuclei
     - H$_2$O deposits (goes directly from vapor to ice) onto deposition nuclei
  2. Contact nuclei
     - Bump into liquid H$_2$O that is supercooled (T < 0°C) and aid H$_2$O to form lattice-crystal structure of ice
     - Supercooled water immediately freezes upon contact with these nuclei
       - Examples: bacteria, clay dust, other ice crystals

Large field project in July 2002 to study Ice Nuclei in tropical anvils

Formation of Snow Flakes

Any tiny liquid water droplets here are “supercooled”

Supercooled water droplets will either (1) freeze upon contact with Ice Nuclei, or (2) evaporate & deposit onto ice crystal surface via Bergeron Process

Only ice crystals here; can fall through cloud and grow by Bergeron Process

Formation of Snow Flakes

Falling ice crystals may freeze supercooled droplets on contact (primary), producing larger ice crystals.

Falling ice particles may collide with form smaller ice particles

Falling ice crystals may collide and stick to other ice crystals (aggregates), producing snowflakes.
“Habits” (types) of ice crystals

- Shape of ice crystal is determined mainly by temperature
  - Ice has a lower saturation vapor pressure, for a given temperature, than water
  - Thus ice crystals grow at expense of water droplets
- Chart shows shape of ice crystal that will form for given temperature
- Explains the various shapes of snow

Why would we care about snow microphysics?

- Understanding snow microphysics can make (or break!) a successful snow forecast
  - How many inches of snow will people observe?
  - Will it be a “heavy, wet” snow? Light and fluffy?

Snowfall densities: all about microphysics
Measuring snow!

- Key points:
  - Site a snow board in a good place
  - Measure however often you want, but only clear the board every 6 hrs (NWS guidelines)
  - Report two numbers
    - New snow (since last time the board was cleared)
    - Snow on ground
  - I also report “storm total snowfall” (the sum of my 6-hrly measurements)

http://www.wdtb.noaa.gov/courses/winterawoc/lessons.html

Four types of precipitation

1. Snow
2. Sleet
3. Freezing rain
4. Rain

- Precip type at surface highly dependent on vertical temperature structure in & below the cloud:
  - $T_{air}$ is $< 0^\circ$ C entirely: snow
  - $T_{air}$ is $> 0^\circ$ C near sfc: rain
  - $T_{air}$ is $> 0^\circ$ C in a layer above the surface but $< 0^\circ$ C at the surface: either freezing rain or sleet

Snow

Forms when entire atmospheric column is below freezing
Snow along the Trans Labrador Highway in Quebec, Canada

Most favorable temperature for snow formation: -10°C to -15°C, when saturation vapor pressure difference is greatest.

Snow melts to rain
- Rain re-freezes before reaching surface
- Falls as pellets of ice

Sleet Sounding
- Warm layer is elevated; liquid can re-freeze before striking

Freezing Rain Sounding
- Surface cold layer is too shallow to re-freeze liquid precip
- Snow melts to rain
- Rain never re-freezes before reaching surface
- Surface objects (cars, grass, power lines) all below freezing; liquid freezes on these surfaces
Other precipitation types

- Frozen (covered in later lesson on svr weather)
  - Graupel
  - Hail
- Precip that doesn’t reach the ground
  - Virga

Remote sensing techniques

- Doppler RADAR
- Satellites: geostationary, polar orbiting
  - Tropical Rainfall Measuring Mission
    - TRMM
TRMM satellite data 23 Feb 2009

Example: TRMM satellite image
Hurricane Katrina: 28 Aug 2005
Category 5 intensity

Notice the limited “swath” of polar-orbiting satellites when compared to geostationary satellites