Precipitation

ATS 350
Chapter 7
Outline

• Other ways that clouds can form (other than instability/convection)

• How is precipitation generated?
  – Warm clouds (T>0°C)
  – Mixed phase clouds containing water and ice (0°C>T>-40°C), a special cloud type, mainly convective clouds
  – Ice only clouds (T<0°C)
Four Different Ways that Clouds Can Be Produced

The concept of stability is directly tied to convection, one of the 4 ways

Convection

Orographic lifting

Notice, all are associated with rising motion which is conducive to cloud formation.
Clouds with Orographic Uplift

This is why Fort Collins is so dry compared to west side of Rocky Mountain National Park

- As air is forced upwards over a mountain range, it expands and cools and reaches 100% RH (dewpoint temperature = actual temperature)
- Any excess water vapor that exceeds the saturation vapor pressure is condensed out and falls out as precipitation
- As the air descends the other side, it contains much less water vapor, and warms by compression (at 10°C/km)—Chinook winds, “snow eater”
A front is a contrast in air masses, denoted by temperature and moisture changes.
How is Precipitation Actually Generated?

• Warm clouds (T>0°C)
• Mixed liquid and ice clouds (0°C>T>-40°C)
• Ice clouds (T<0°C)
• A cloud is said to be glaciated when it contains only ice. Clouds colder than -40°C are said to be glaciated. Even pure water freezes at this cold temperature.

**Precipitation:** Any form of water particles (liquid or solid) that falls from the atmosphere and reaches the ground.
1) Precipitation in Warm Clouds

- First step is to generate cloud droplets
- This occurs when sufficient cooling takes place such that the atmosphere reaches 100% RH (e.g. by lifting, convection, or radiative cooling)
- **Cloud condensation nuclei (CCN)/aerosols aid in cloud drop development (e.g. salt)**
- Because volume is given by
  \[
  \frac{4}{3} \pi r^3
  \]
  about 1,000,000 cloud droplets 20 microns in diameter are needed to form a raindrop 2 mm in diameter (how this occurs we will discuss below)

Recall 1 micron is $10^{-6}$ meters
1) Precipitation in Warm Clouds
(Why 100% Relative Humidity Is Not an Rigid Threshold for Droplet Growth)

• In reality, vapor pressure over a curved surface like a small droplet is greater than that over a flat surface. Thus, the humidity required for a small droplet to be in equilibrium with the vapor, that is, not evaporate, requires a ambient humidity in excess of 100%. These humidity values are rare in the atmosphere

• But, CCN make it such that water can begin condensing at relative humidity values less than 100% (effectively lowering the humidity required to form a droplet), which makes droplet growth occur sooner

Small droplet here is less than 1 micron in diameter.
A CCN particle, cloud condensation nucleus is any aerosol particle in the atmosphere that is soluble in the presence of water. Sulfates and nitrates dominate.
Generation of Droplets in a Cloud Jar

First, try to generate a cloud without aerosols in the jar (no smoke)

- First, air is pumped into the jar to achieve a pressure greater than that outside.
- Air is rapidly let out, expands adiabatically, cools, and reaches 100% RH (just like a rising air parcel)
- No cloud droplets form, because no CCN are present on which to condense water.
Second, add some smoke (aerosols) to the jar

- Air is pumped into the jar.
- Air is rapidly let out, expands adiabatically, cools, and reaches 100% RH (just like a rising air parcel)
- Cloud droplets form, because CCN are present to aid cloud droplet formation.
1) Collision and Coalescence of Cloud Drops Needed to Produce Precipitation in Warm Clouds

- Growth by condensation from vapor to liquid phase would take many hours to produce large enough particles to precipitate. Clouds do not last this long.

- Thus, collision and coalescence of cloud drops is needed to form larger drops that can precipitate.

- Process is aided by updrafts, thick clouds, disparate drop sizes, and opposite charged drops.

- This condition is really active in the tropics!
1) Collision and Coalescence Aided
Because Large Drops Have Larger Terminal Velocity than Small Drops—why don’t raindrops get infinitely large??

Terminal velocity: Downward velocity achieved when downward force due to gravity equals upward drag force due to air
1) Warm Rain Formation Favored By:

- Wide range of drop sizes (big drops overtake small ones)
- Thick clouds (more chances for collisions of large and small drops)
- Fast updrafts
- A broad size range of droplets can form when small and large (sea salt) aerosols are present over the world’s warm ocean areas!
2) Generation of Precipitation by Mixed Liquid and Ice Clouds (0°C>T>-40°C)

• Large ice particles that can reach the ground as precipitation grow in the following ways:
  – Growth by vapor deposition
  – Rimming/accretion
  – Aggregation

• Most precipitation we experience, even during the summer, depends on growth in mixed phase clouds. Rain arrives at the ground but is formed from melting ice grown aloft in the clouds.
2) Generation of Precipitation by Mixed Liquid and Ice Clouds (0°C>T>-40°C)

- Liquid droplets can exist to about -40°C in the absence of ice nuclei which are required for the droplet to freeze.
- These drops that exist at temperatures below 0°C are called supercooled drops.
- Ice nuclei are limited in the atmosphere, and therefore at temperatures between 0°C and -40°C, a mixture of liquid drops and ice crystals is usually present.
- Shattered ice crystals can provide ice nuclei in clouds that are older. Other ice nuclei include some clay mineral particles, bacteria, plant leaf material, and ?? Ice nuclei are insoluble!
- Artificial ice nuclei, used for cloud seeding, include dry ice and silver iodide. These work via very different methods.
- Cloud seeding is a science full of mystery and uncertainty!
2) Example of Ice Nucleus Seeding from Above
2) Mixed Clouds: Deposition

- Recall, that the saturation vapor pressure is higher over liquid than over ice at the same temperature.
2) Mixed Clouds: Deposition

- Recall, that the saturation vapor pressure is higher over liquid than over ice at the same temperature.
- Thus, where ice crystals and supercooled drops coexist, vapor will want to migrate from liquid to ice (by diffusion).
- The excess vapor over ice exceeds the saturation vapor pressure, and deposition occurs, and the ice crystal grows.
- This ice growth is very rapid, and at the expense of the supercooled drops.
- This process is usually referred to as the “Bergeron-Findeisen” process.
2) Mixed Clouds: Deposition

- Ice crystals like the ones on the right grow through this process of deposition.
- The intricate snow crystals shown here are just a few examples of the ice crystals shapes that form in the atmosphere via deposition.

The shape of the crystal depends on both temperature and humidity relative to ice.
2) Mixed Clouds: Riming/Accretion

- Ice crystals fall faster than cloud drops.
- Ice crystals can collide with supercooled water drops, and grow by “riming” or “accretion”.
- The generation of hail is an extreme example (which requires strong updrafts to elevate an iceball of those sizes).
2) Mixed Clouds: Riming/Accretion

Hail is a result of riming/accretion process

World’s largest hailstone, July 2010, Vivian South Dakota
8 inches average diameter
~ 2 pounds
2) Mixed Clouds: Aggregation

• Individual ice crystals may stick together, forming an aggregate of crystals that reach the ground or form liquid drops.
• Most of our big snowflakes we see are aggregates of numerous ice crystals.
• Crystals most likely to stick when a liquid water layer resides on the crystal surface which increases with temperature.
• These aggregates melt, and actually form most of our raindrops during all seasons.
Precipitation types

- Rain that evaporates before reaching the surface is termed *virga*
  - Common in Colorado’s dry climate
Precipitation types

- Precipitation reaching the surface can take on different forms depending on the vertical temperature profile.
- Examples here are given for snow, sleet, freezing rain, and rain.
Freezing rain and riming

- Freezing rain coats surfaces with large quantities of ice
  - Trees break, power lines fall, roads are treacherous
- Supercooled cloud drops collected by trees (or other structures) are known as rime
- Collection of supercooled rain and cloud drops poses a hazard in the form of aircraft icing

Mt. Washington, NH
3) Cold Clouds (T<0°C)

- An example of these are cirrus clouds at very high elevations. Crystals form via deposition on ice nuclei.
- Other types of cold clouds form around frontal zones where cloud updrafts are relatively weak, not permitting mixed phase conditions from forming.