Precipitation

GEOG/ENST 2331 – Lecture 11

Ahrens: Chapter 7

Last lecture: Prior to Study week

- Atmospheric stability
- Condensation
  - Cloud condensation nuclei (CCN)
- Types of clouds

Precipitation

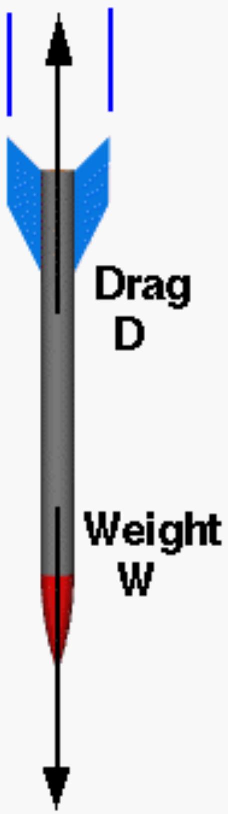
- **Why clouds don't fall**
  - **Terminal velocity**
  - **Growth by condensation**
  - **Collision-coalescence**
- Cold clouds
  - **Bergeron process**
  - **Types of precipitation**
- Precipitation
- Hail
- Colour in the daytime sky

Terminal velocity

- Galileo: all objects fall at the same speed
  - Yes ... true in a vacuum
- Friction: aerodynamic drag opposes falling movement
  - Friction increases as speed increases
  - Balance of forces: friction equals gravity
- Size, shape and mass
- Eventually friction matches gravity and acceleration stops
- Hail examples

Terminal velocity

Forces



Net Force equals Drag minus Weight.

$$F = D - W$$

Drag Equation:

$$D = Cd \frac{\rho V^2 A}{2}$$

V = velocity
ρ = gas density
A = frontal area
Cd = drag coefficient

Drag increases with the square of the velocity.

When Drag is equal to Weight there is no net force on the rocket.

$$F = D - W = 0$$

Then:

$$Cd \frac{\rho V^2 A}{2} = W$$

Terminal Velocity:

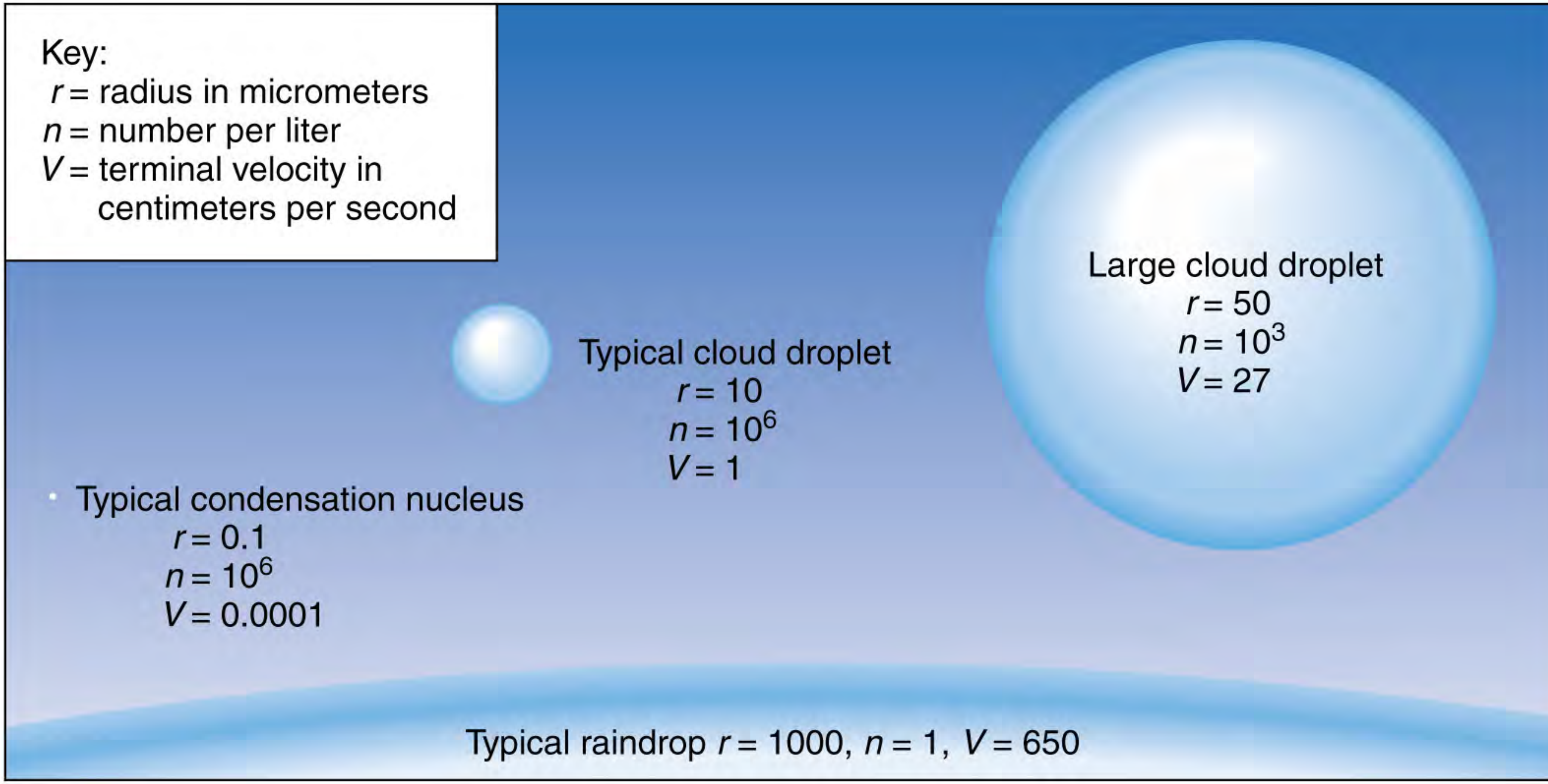
$$V = \mathrm{sqrt}\left(\frac{2\ W}{Cd\ \rho\ A}\right)$$

Comparing two objects, the higher velocity occurs for greater weight, lower drag coefficient (more steamlined), lower gas density (higher altitude), or smaller area.

Objects do <u>not</u> fall at the same rate through the atmosphere.

Figure credit NASA

Sizes of cloud droplets



A&B: Figure 7-2

Growth by condensation

- Starts with condensation around CCN
- Droplets only grow to about 20 μm through condensation
  - Too many droplets, not enough water
- Too small to generate precipitation

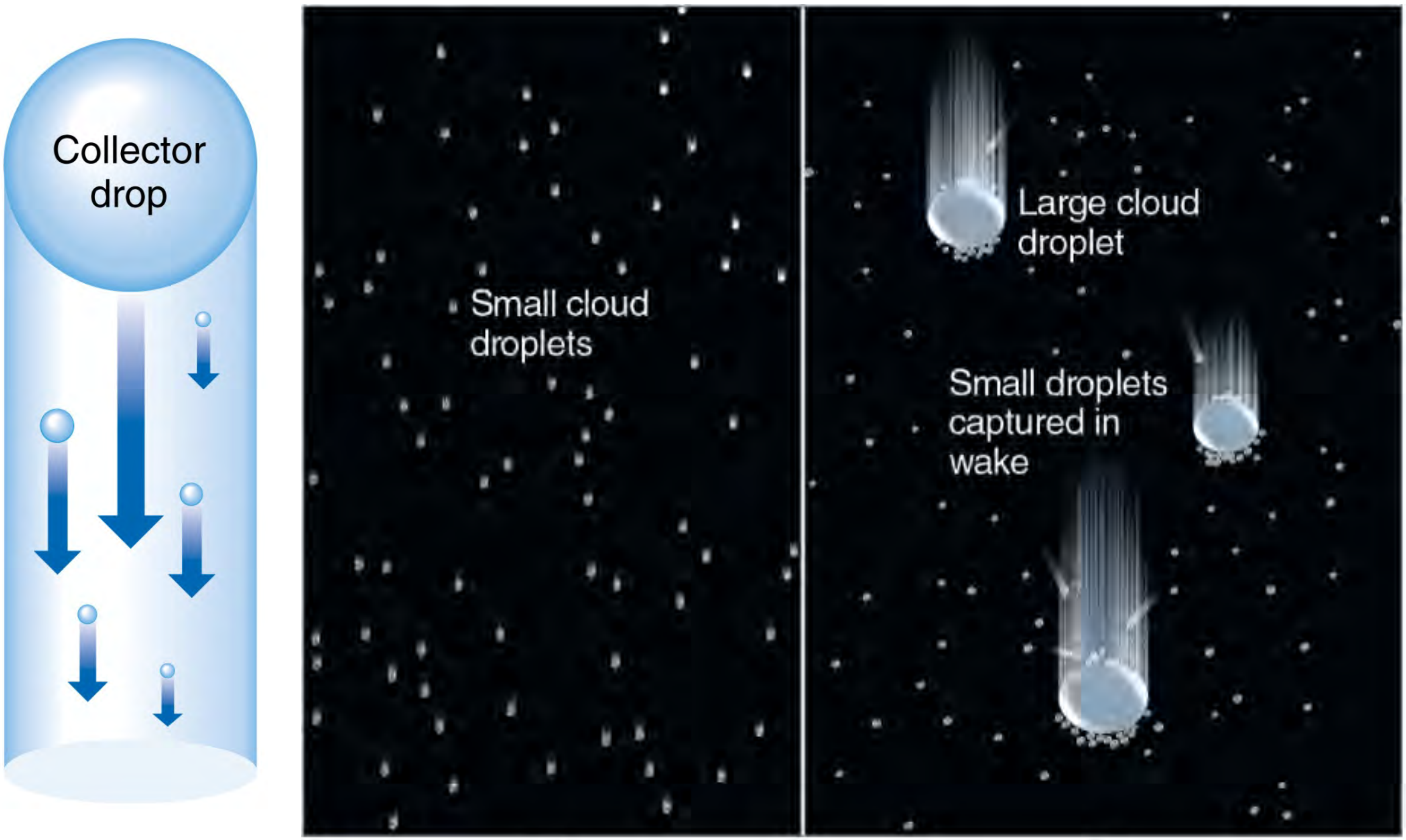
Growth in warm clouds

- Clouds with temperatures above freezing dominate tropics and mid-latitudes (during the warm season)

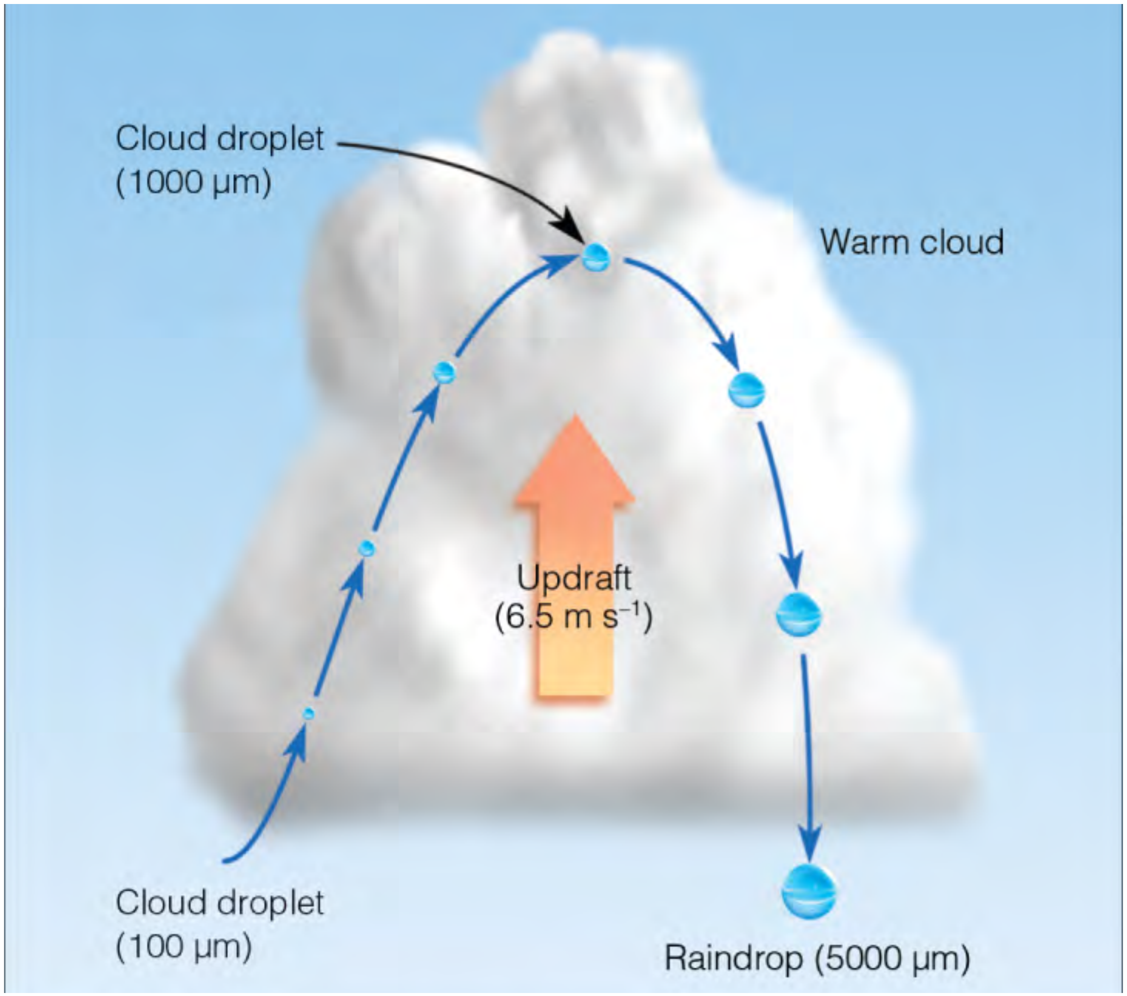
- ***Collision-coalescence*** generates precipitation
- Process begins with large ‘collector’ drops that have high terminal velocities

Collision-coalescence

Ahrens: Fig. 7.5



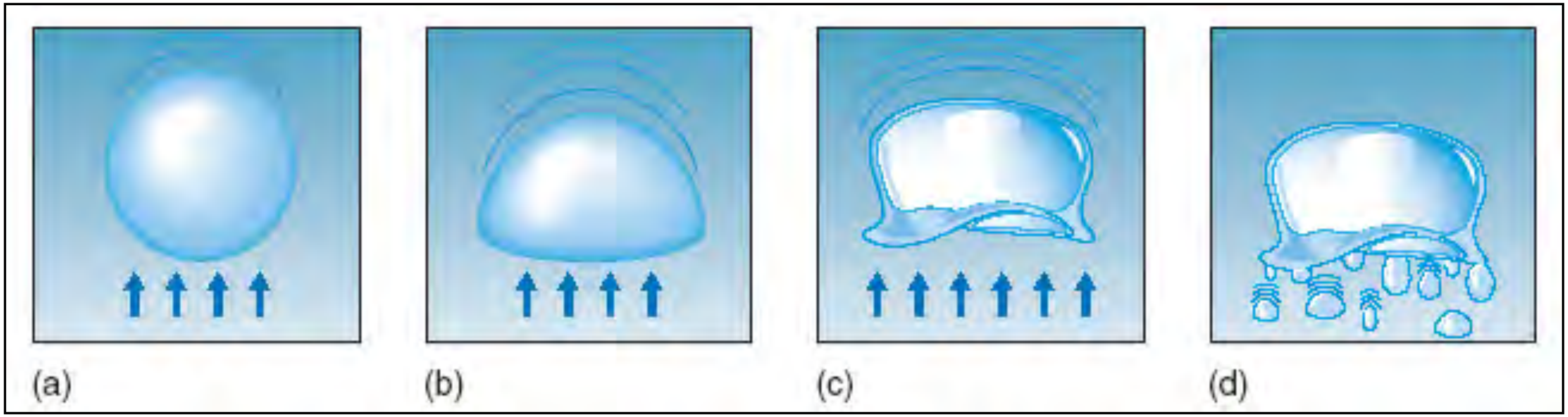
Updrafts and rain



Ahrens: Fig. 7.6

Raindrops

- Typically drops have a radius of 500-5000 μm
- Size limited by effects of air resistance



A&B: Figure 7-16

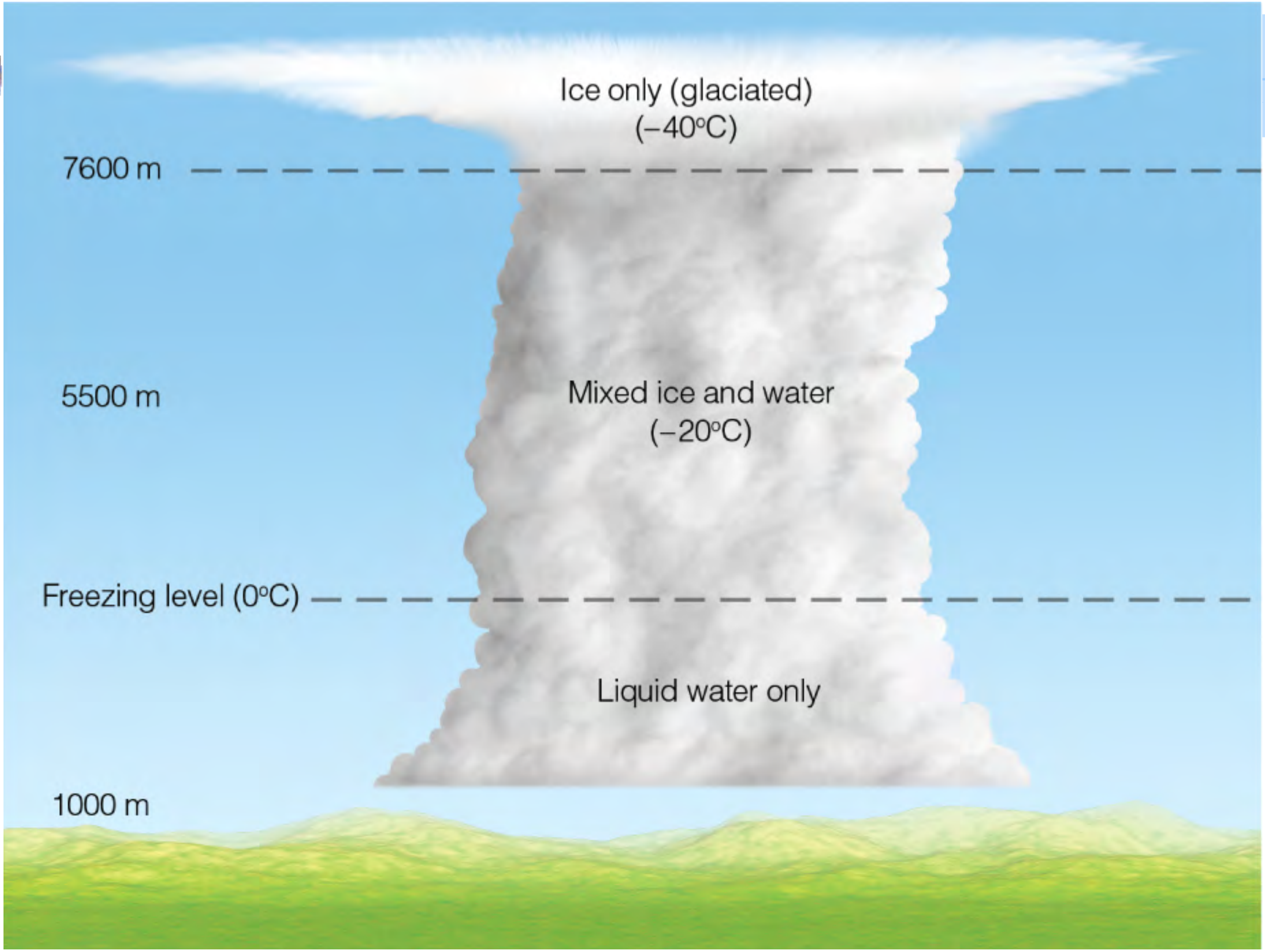
Growth in cool and cold clouds

- High latitudes and mid-latitudes (in cold season)
- Cool clouds
  - Above freezing point at bottom, below freezing at top
  - More water at the bottom, more ice at the top
- Cold clouds
  - Below 0°C throughout
  - Ice and *supercooled* water

A&B: Figure 7-7

Ice nuclei

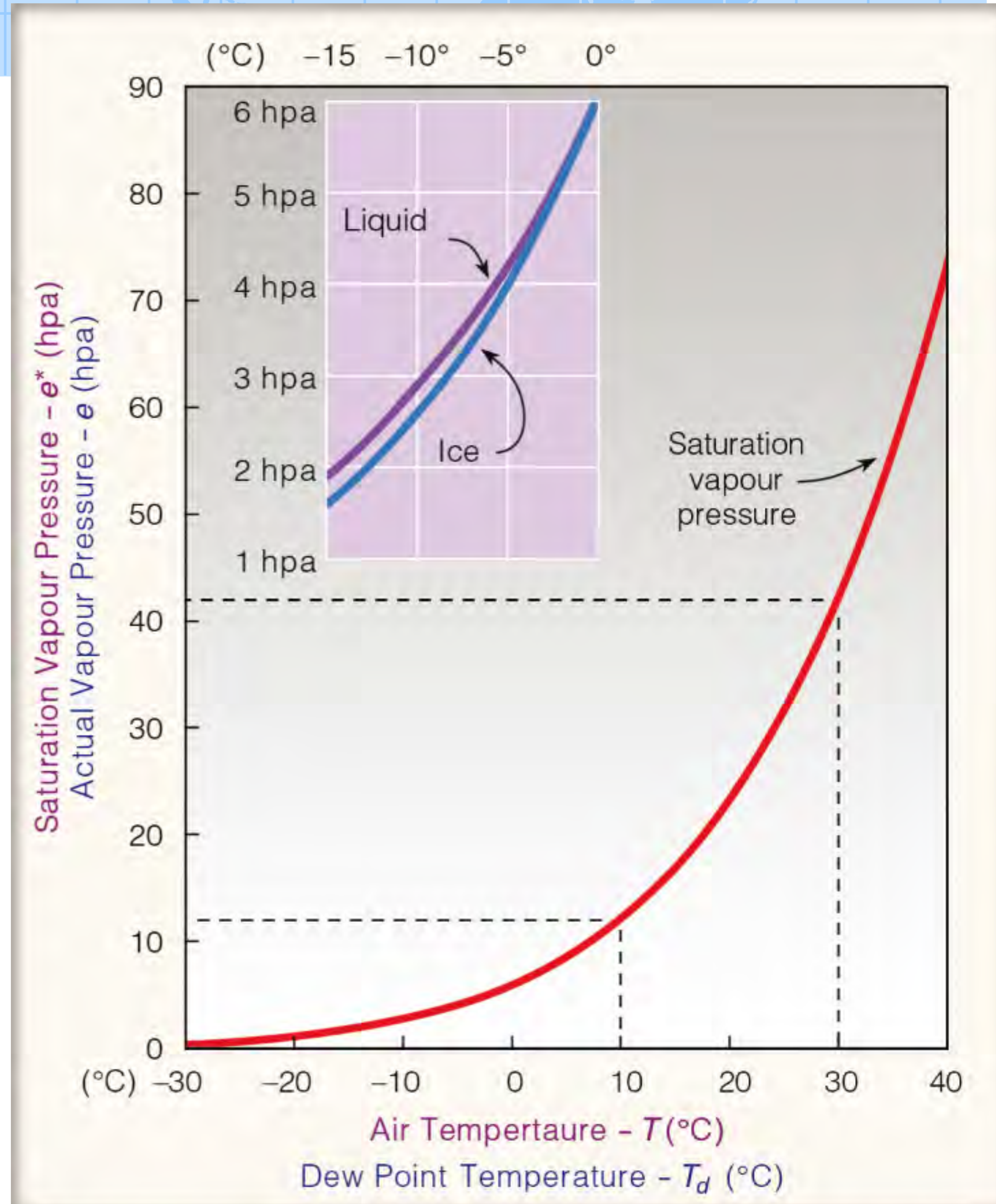
- Different materials than CCN
  - Rarer
  - Often clays
- 0 to -4°C: Clouds contain supercooled water
- -4 to -40°C: Clouds contain a mix of ice and supercooled water
  - Proportion depends on availability of nuclei



Ice and water in cumulonimbus clouds

Ahrens: Fig. 7.7

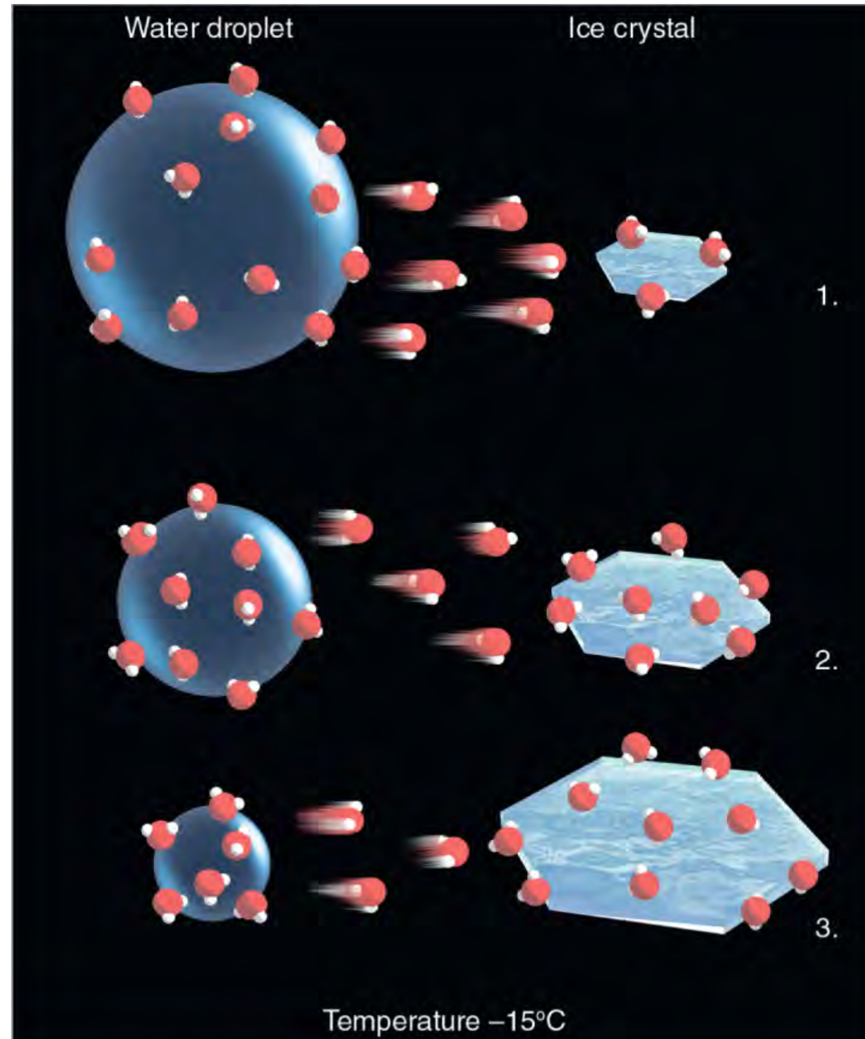
Saturation vapour pressure



Ahrens: Fig 4.10

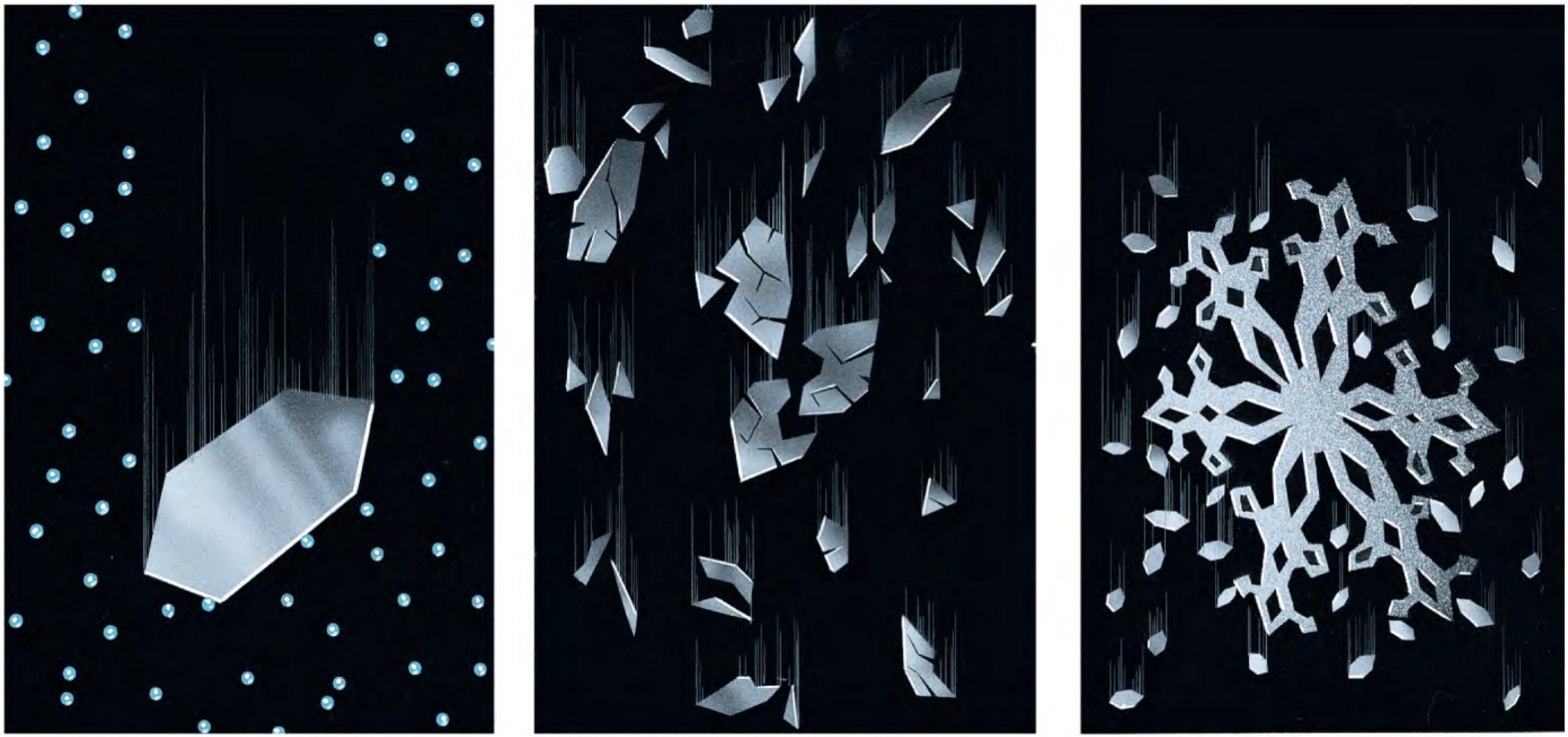
Bergeron process for ice crystals

- Ice has a lower saturation vapour pressure than water
- Net evaporation from water
- Net deposition to ice
- Ice crystals grow while supercooled water droplets shrink



Ahrens: Fig. 7.10

Snowflakes



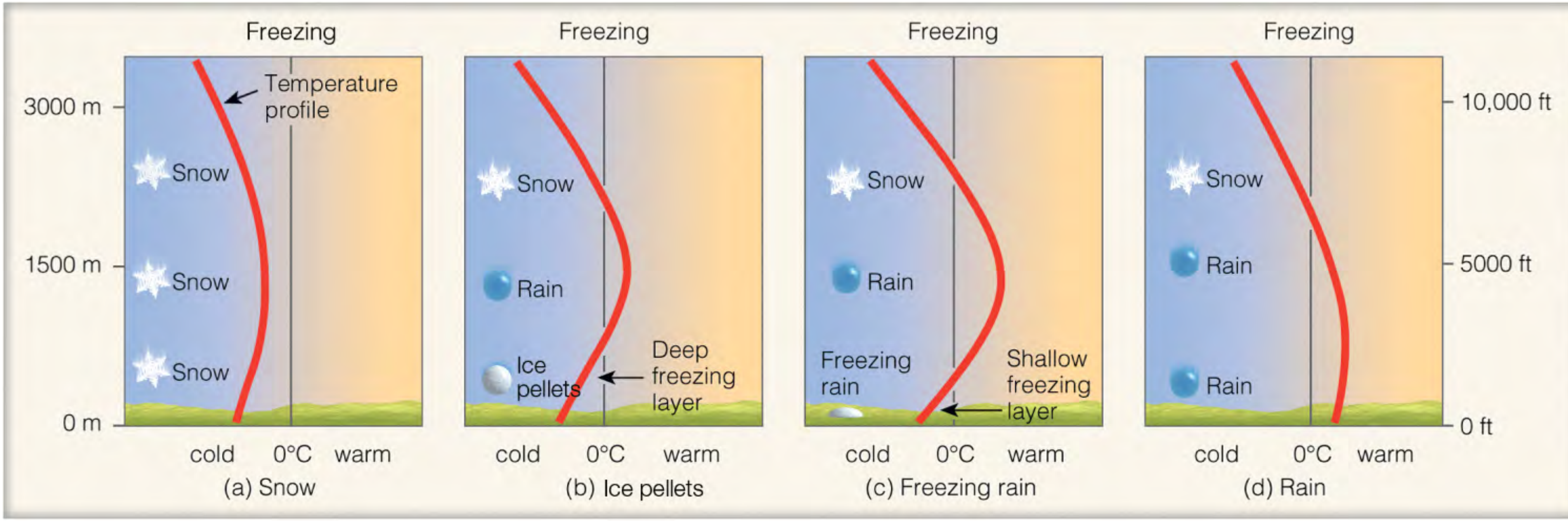
Accretion
Graupel

Fracturing

Aggregation
Snowflakes

Ahrens: Fig. 7.11

Temperature and precipitation



Ahrens: Fig. 7.23

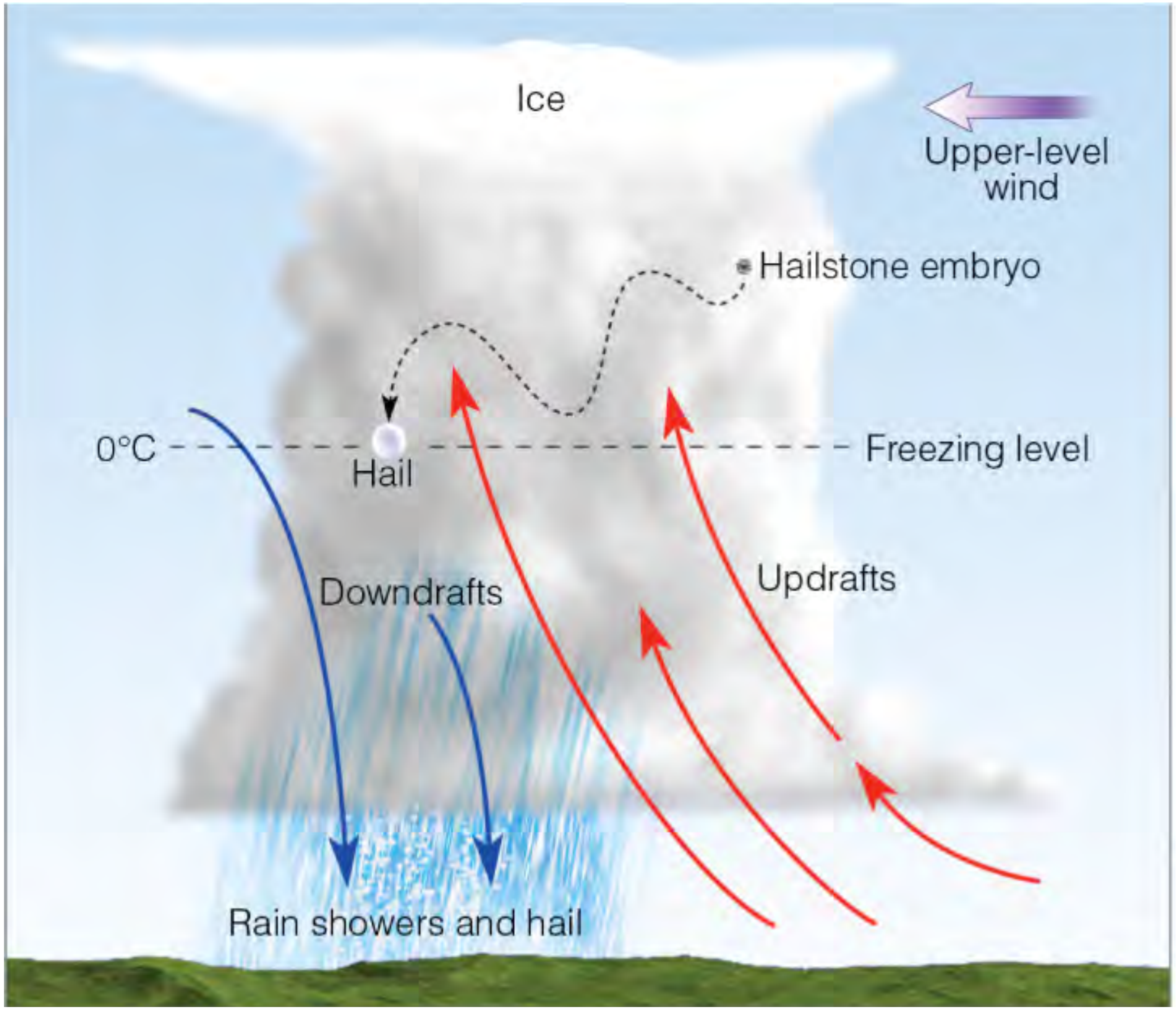
- Precipitation often starts as snow
  - Melts as it falls into warmer air
  - In an inversion, it may melt and re-freeze

Graupel and hail

- Cumulonimbus clouds extending high in troposphere
- Lots of riming (accretion of supercooled liquid drops)
- Forms ice pellets called *graupel*
- Rapid updrafts in thunderstorms recirculate the graupel before they can fall

- Grow in size to *hailstones*
  - Concentric layers of ice
  - Typically less than 1 cm but can grow to over 3 cm

Hail



Ahrens: Active Fig. 7.28

Rain gauge

- Standard radius of 10 cm
- Collects into graduated cylinder
- Tipping bucket: 0.2 mm x # of tips = rain amount

Ahrens: Fig. 7.30, 7.31

Snow gauge

- Similar design
- Can measure snow depth or *water equivalent*

Source: Wikipedia

Snow courses

- Use collection tubes to extract snow at multiple locations
- Density of snowpack is extremely variable
  - Typical fresh snow – 10:1
  - Powder – 30:1
  - Compacted drifts – 2:1

Snow depth sensor

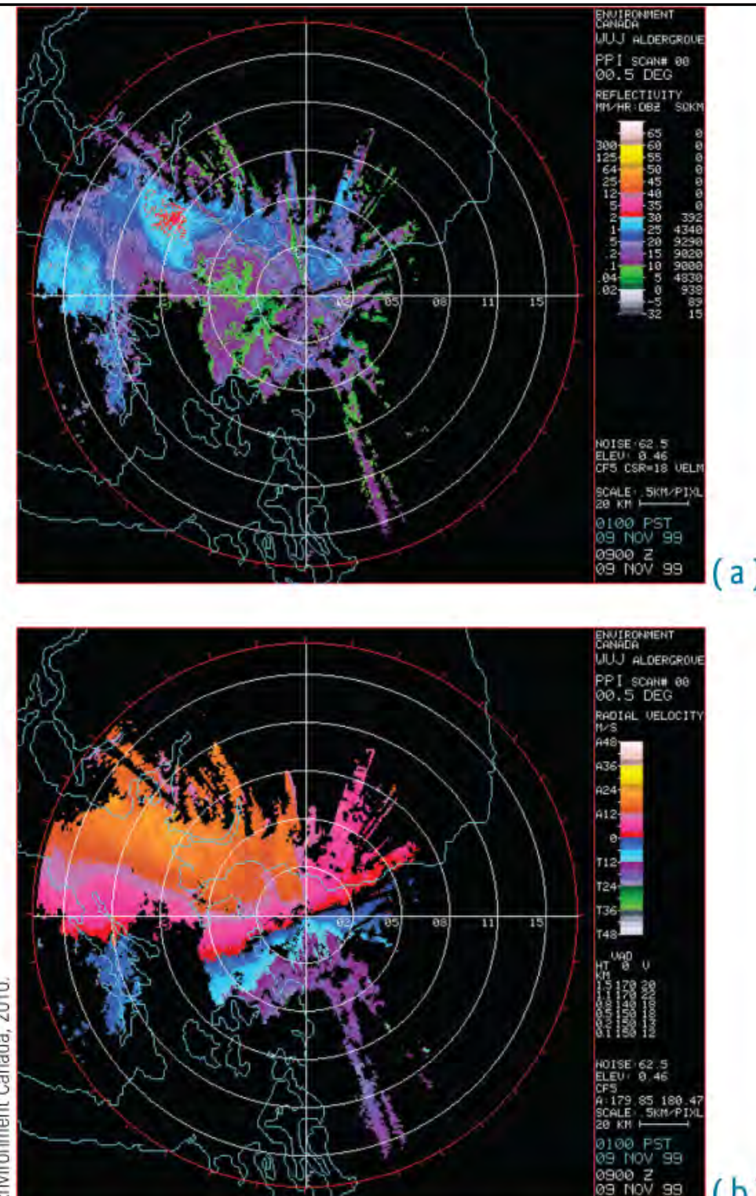
- Acoustic snow depth sensor
- Uses sound waves
- Automated recording for remote locations

Ahrens: Fig. 9, p. 204

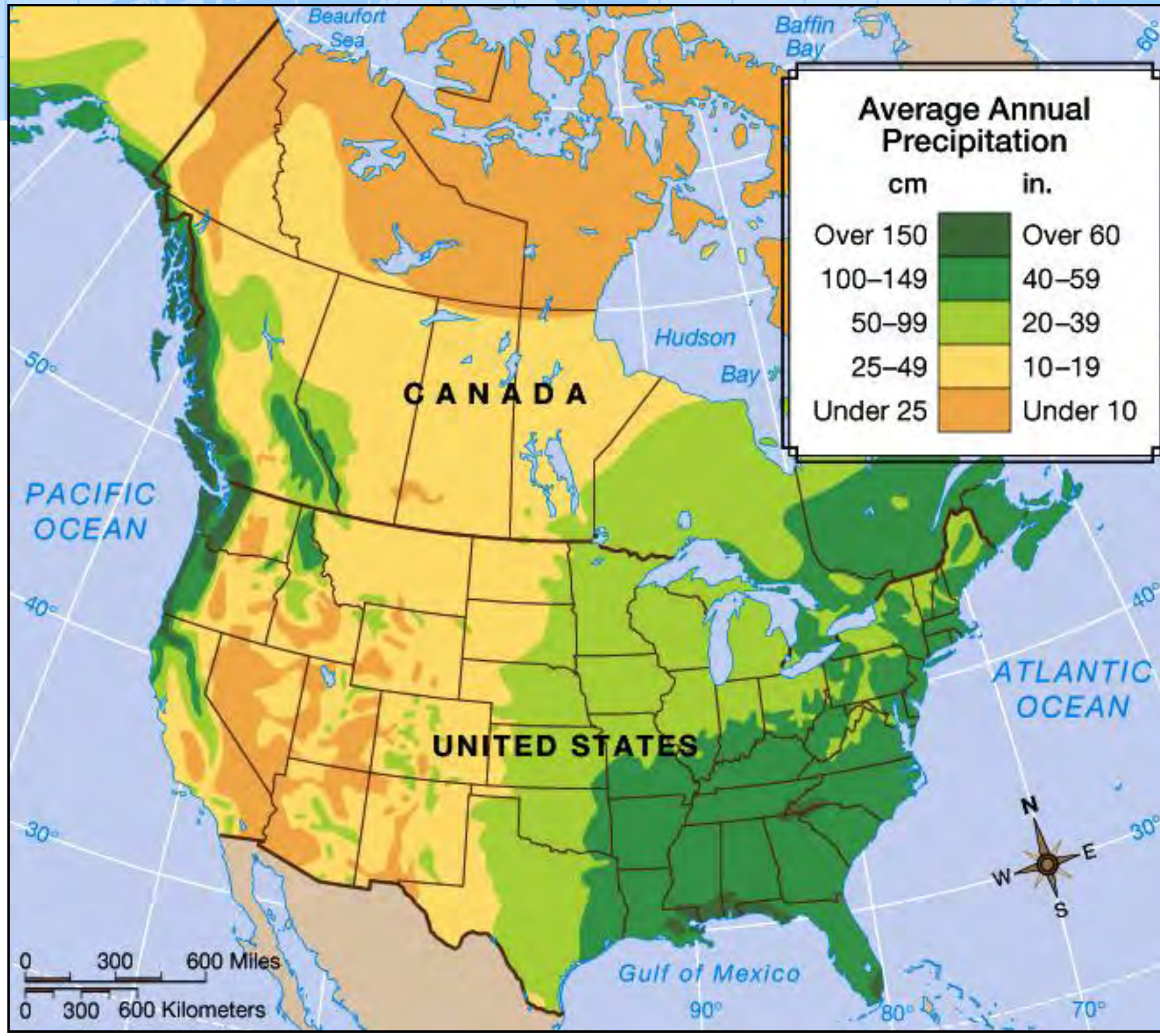
Radar

- Precipitation backscatters microwave radiation
- More intense backscatter implies more intense precipitation

- Doppler radar detects horizontal velocities
  - Wind speed

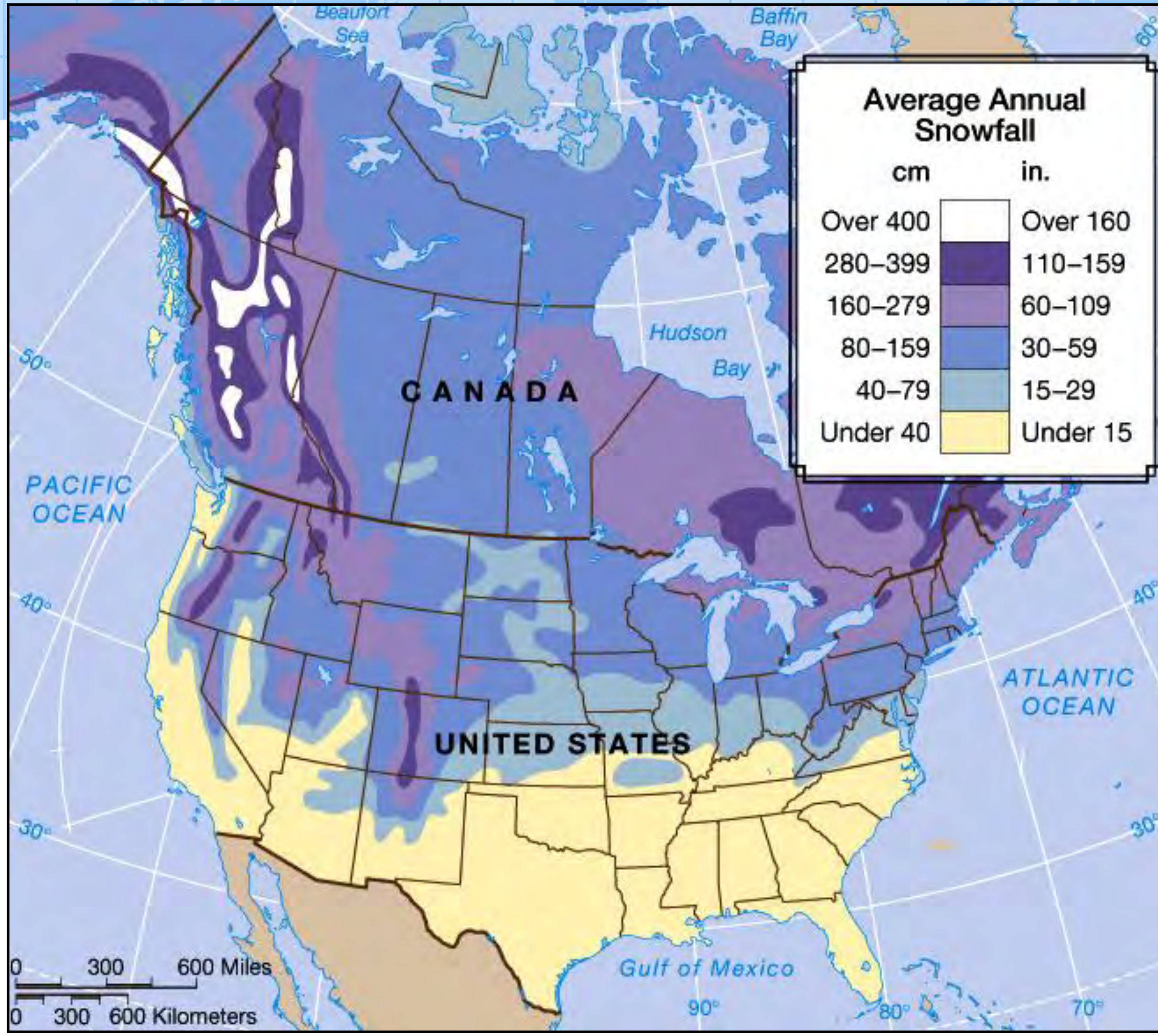


Ahrens: Fig. 7.33



Total Annual Precipitation in Canada and US

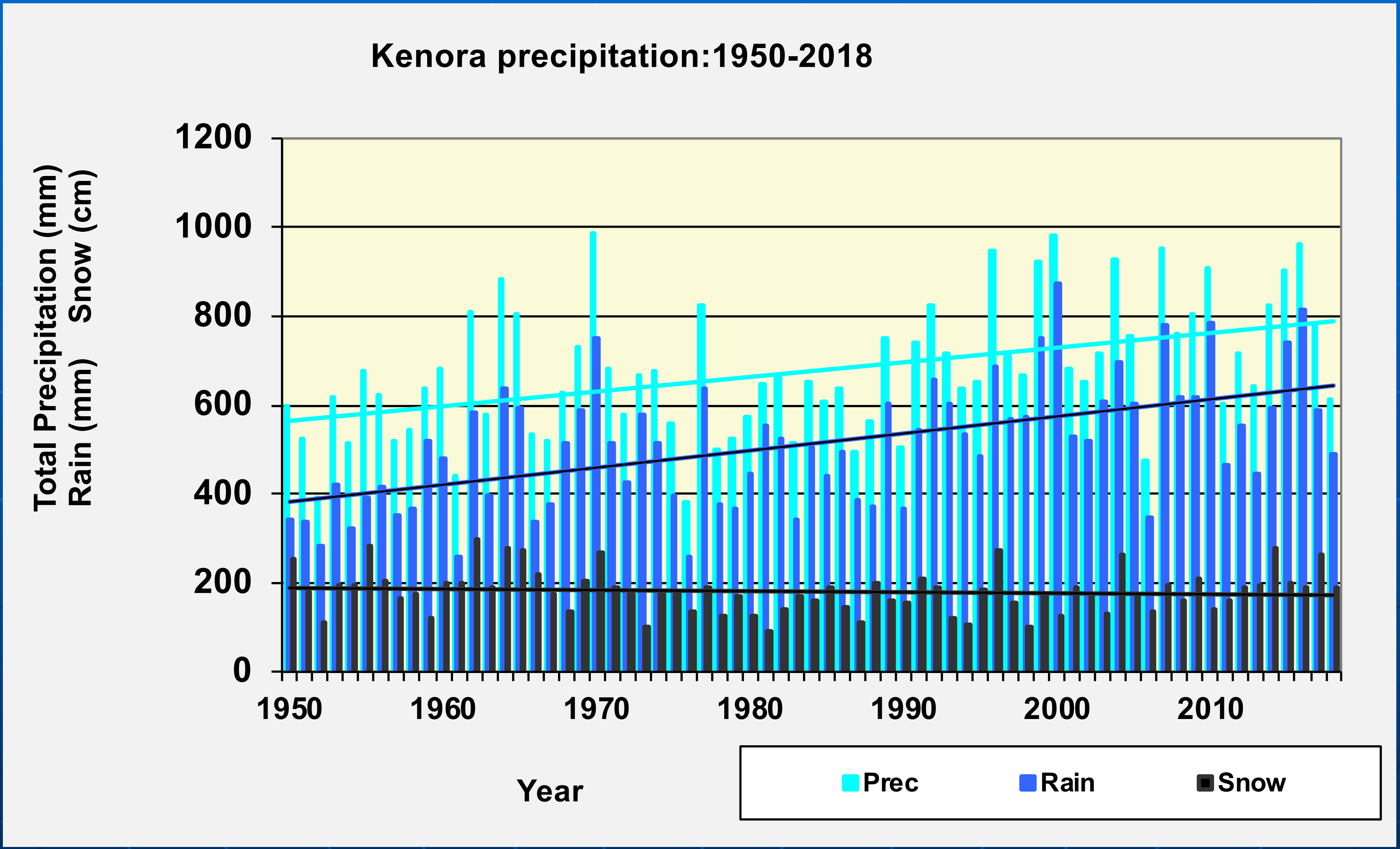
A&B: Figure 7-10



Annual Snowfall in Canada and US

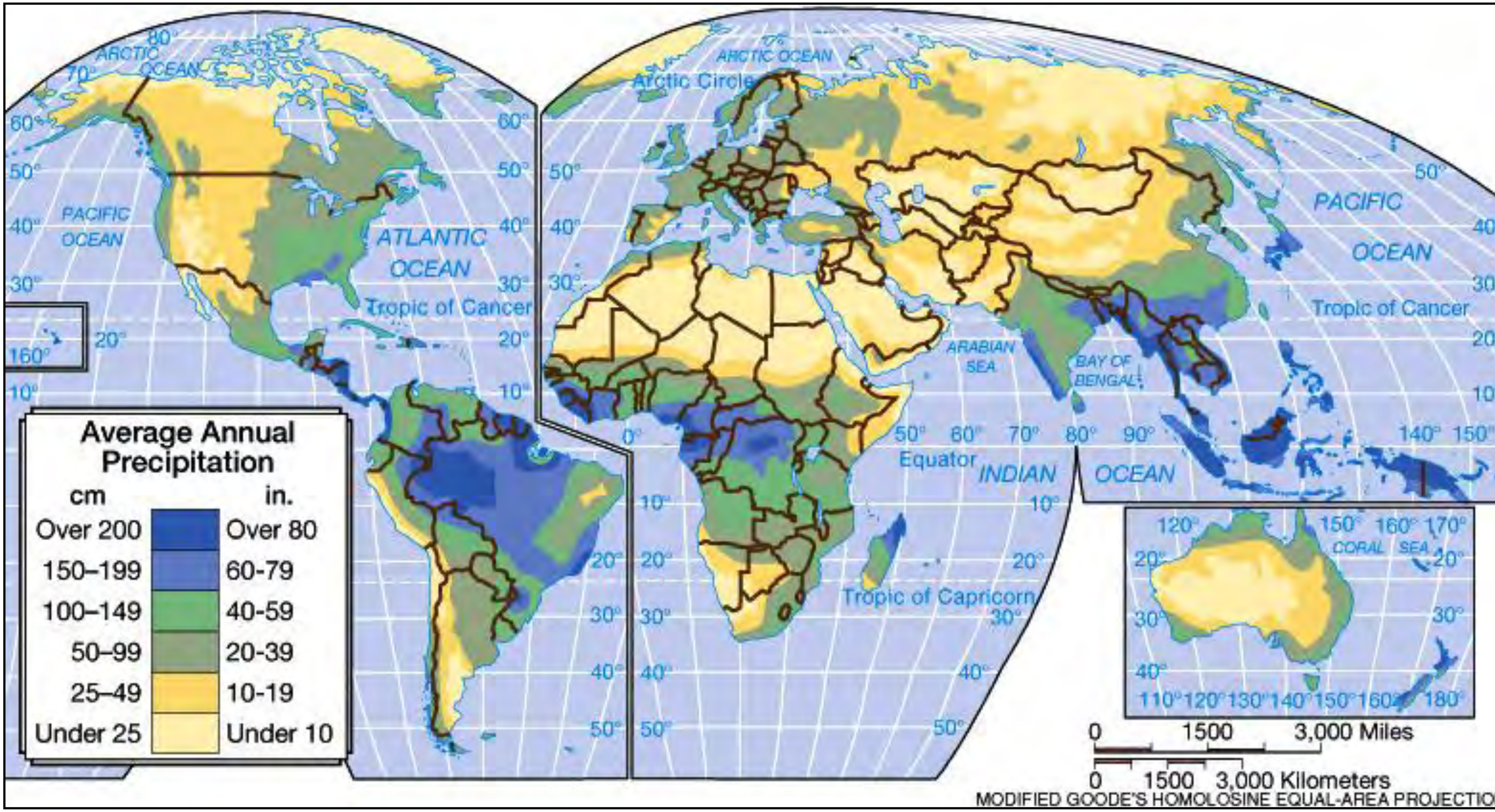
A&B: Figure 7-10

Annual Precipitation: Kenora (1950-2018)



Kenora: Heavy rain events by decade

Rain in mm	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2011 – 2018 (8 years)
50-74	1	3	4	4	6	5	7
75-99	0	0	2	0	1	2	4
100+	0	1	1	1	2	1	0



Total Precipitation Around the World

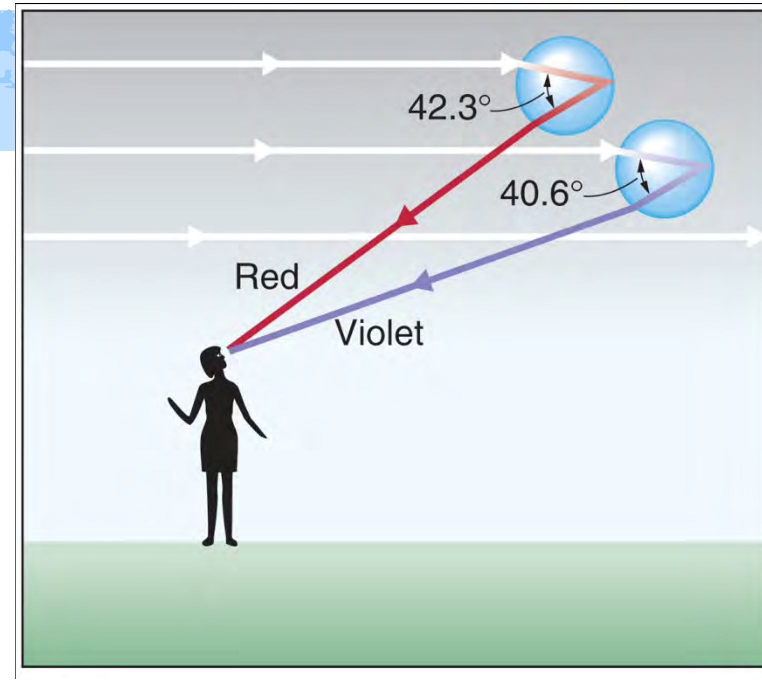
A&B: Figure 7-8

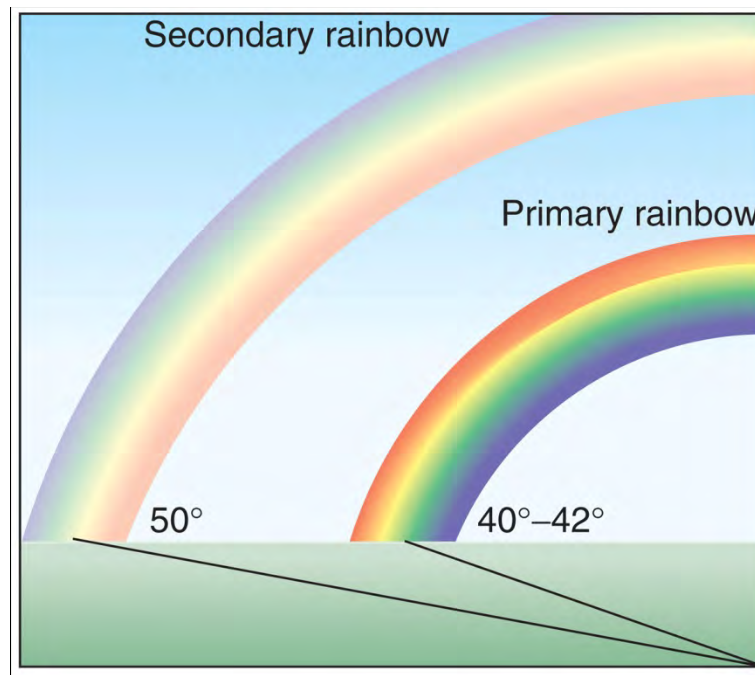
Rainbows (Ahrens Chapter 19)

A&B: Figure 17-7

Rainbows

- Light shining on raindrops
- Some light is refracted (bent) then reflected
- Long wavelengths refract further

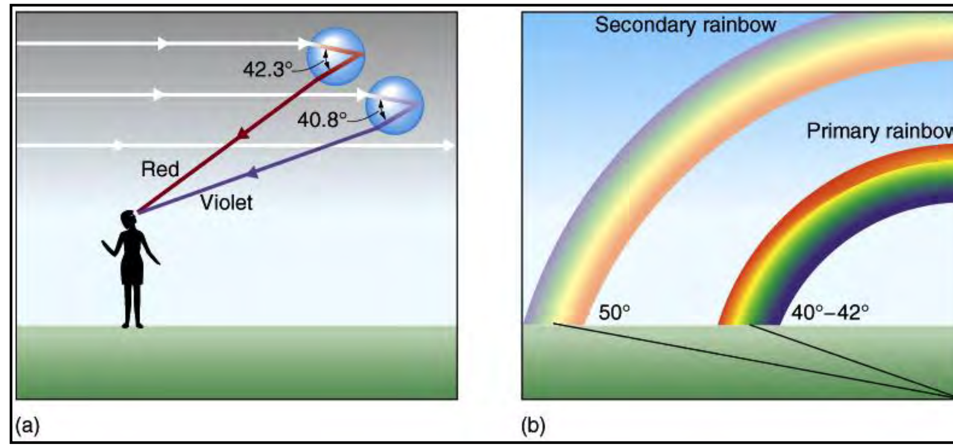


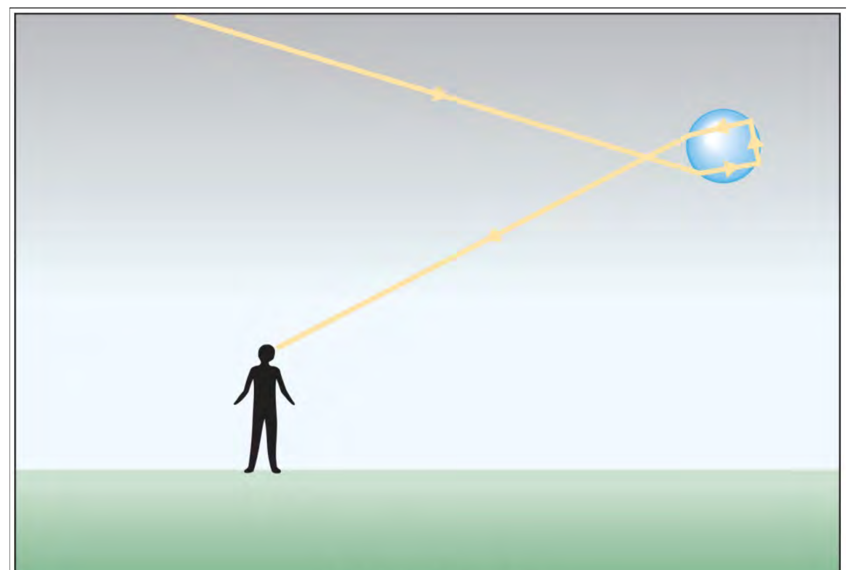


A&B: Figure 17-8

Secondary rainbows

- Reflect twice within the drop
- Different angle from incident light
- Second reflection reverses colours





A&B: Figure 17-8 and 17-9


Mobile Uploads

Glory

Visible from aircraft

Some sunlight scattered straight back

A&B: Figure 17-14


Miigwetch !
Stephanie Baker

Next Lecture

- Winds
- Ahrens: Chapter 9