Precipitation

GEOG/ENST 2331 – Lecture 12

Ahrens: Chapter 7

Last lecture

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

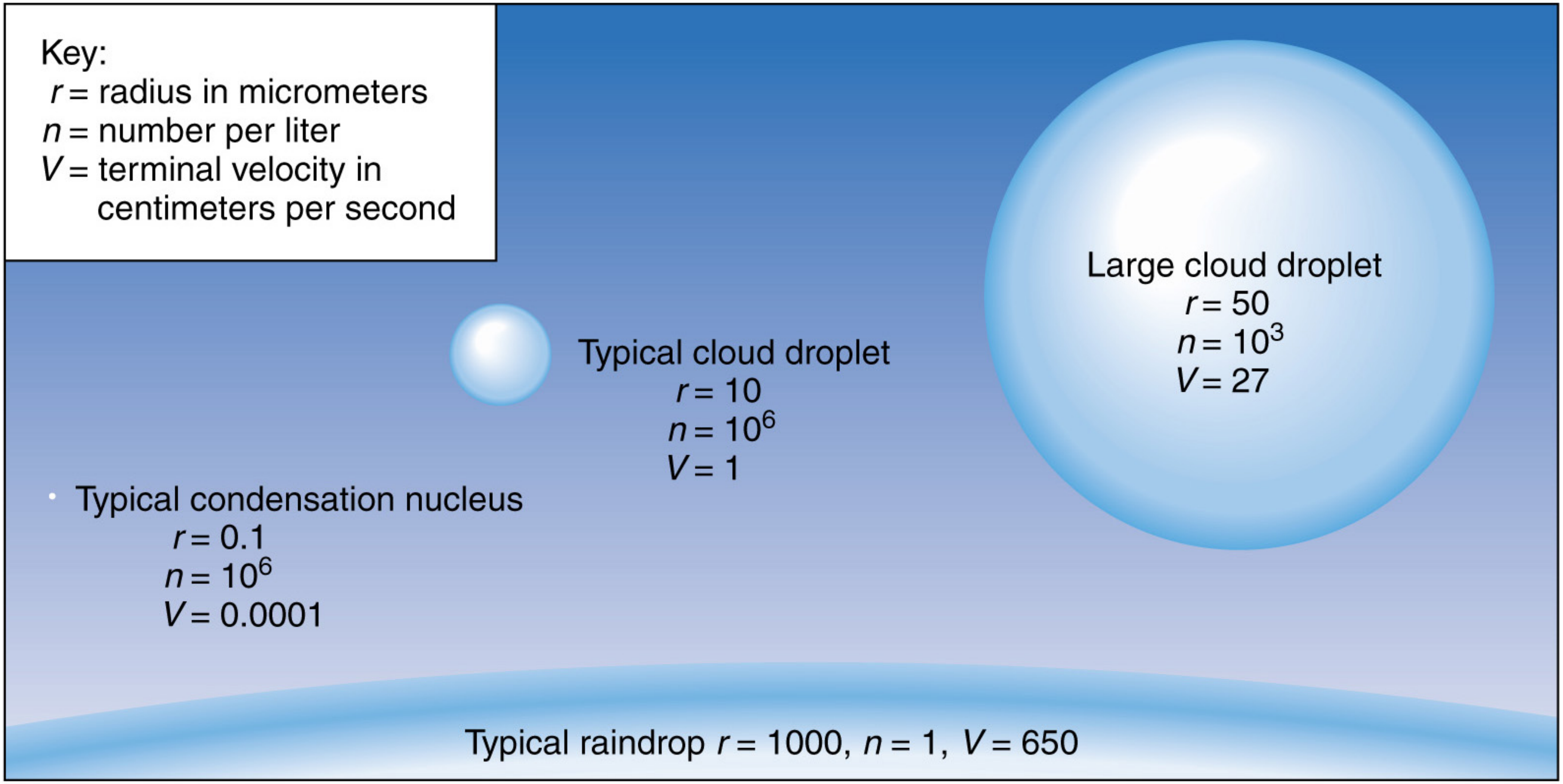
Precipitation

- **Why clouds don't fall**
  - **Terminal velocity**
  - **Growth by condensation**
  - **Collision-coalescence**
- Cold clouds
- Precipitation
- Rainbows

Terminal velocity

- Galileo: all objects fall at the same speed
  - ...in a vacuum...
- Friction: aerodynamic drag opposes falling movement
  - Friction increases as speed increases
  - Balance of forces: friction equals gravity
- *Terminal velocity*
  - Size, shape and mass

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

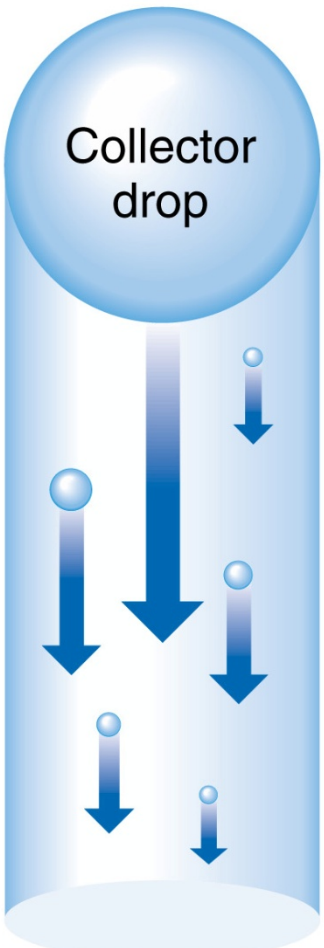
Growth in warm clouds

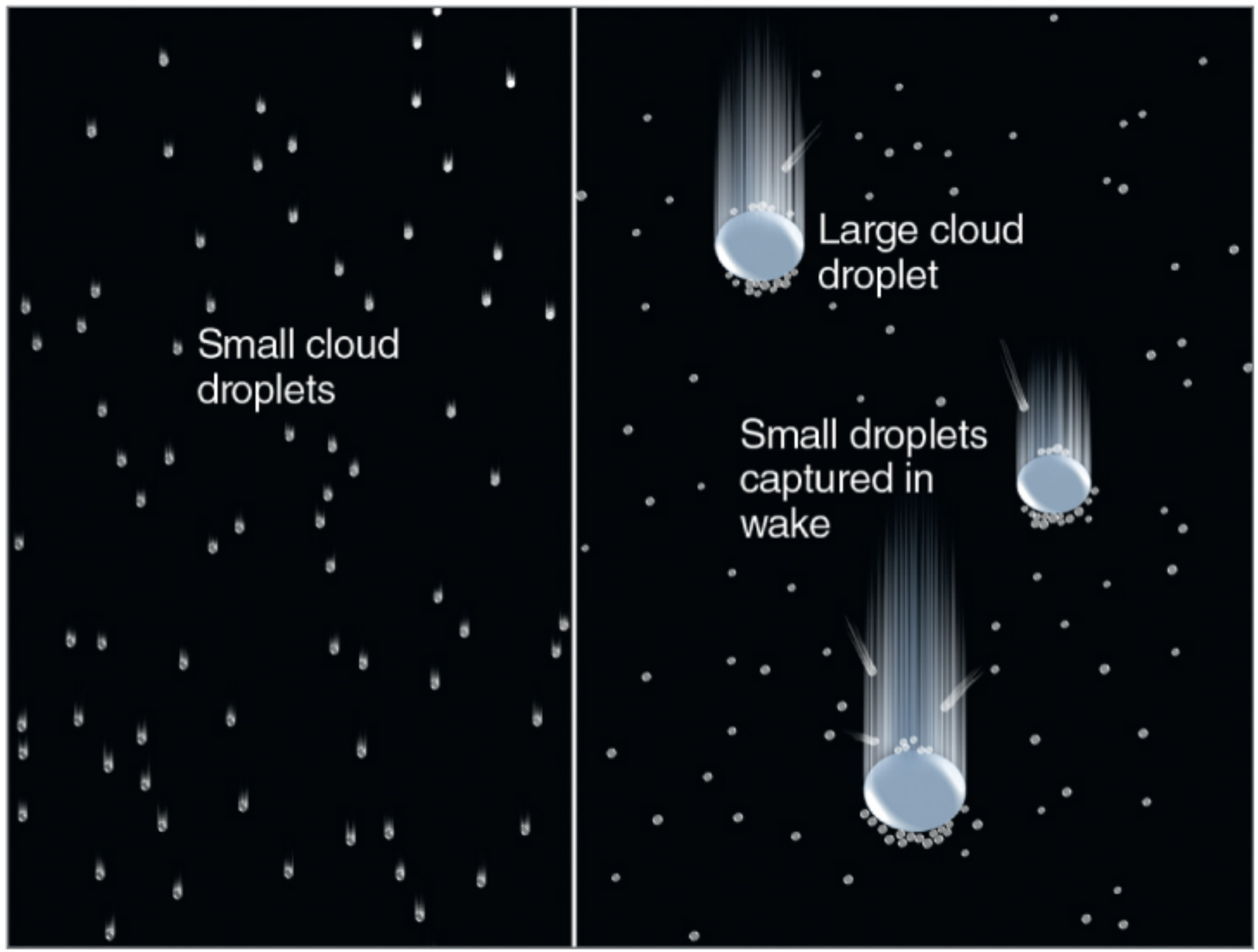
- Clouds with temperatures above freezing dominate tropics and mid-latitudes (during the warm season)

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

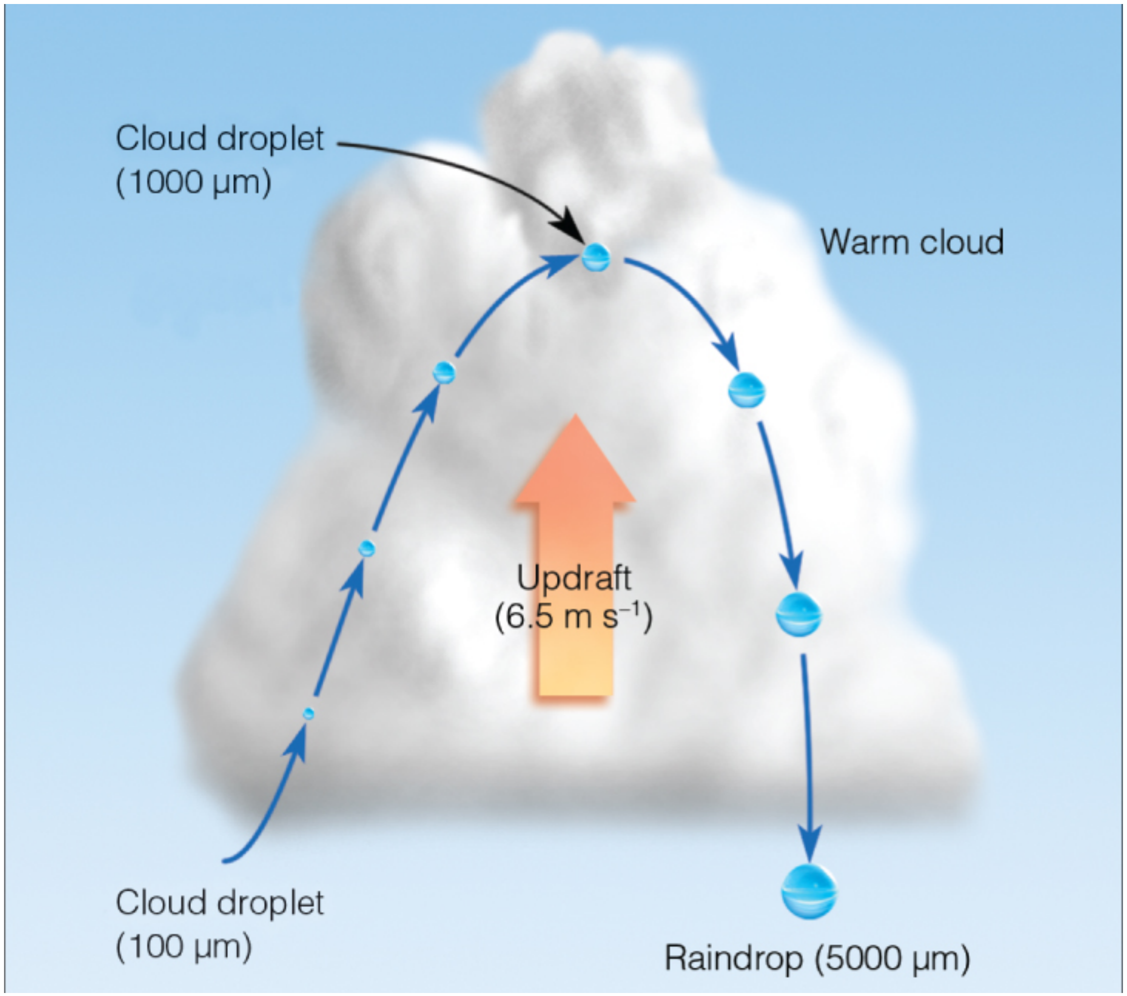
Collision-coalescence

Ahrens: Fig. 7.5





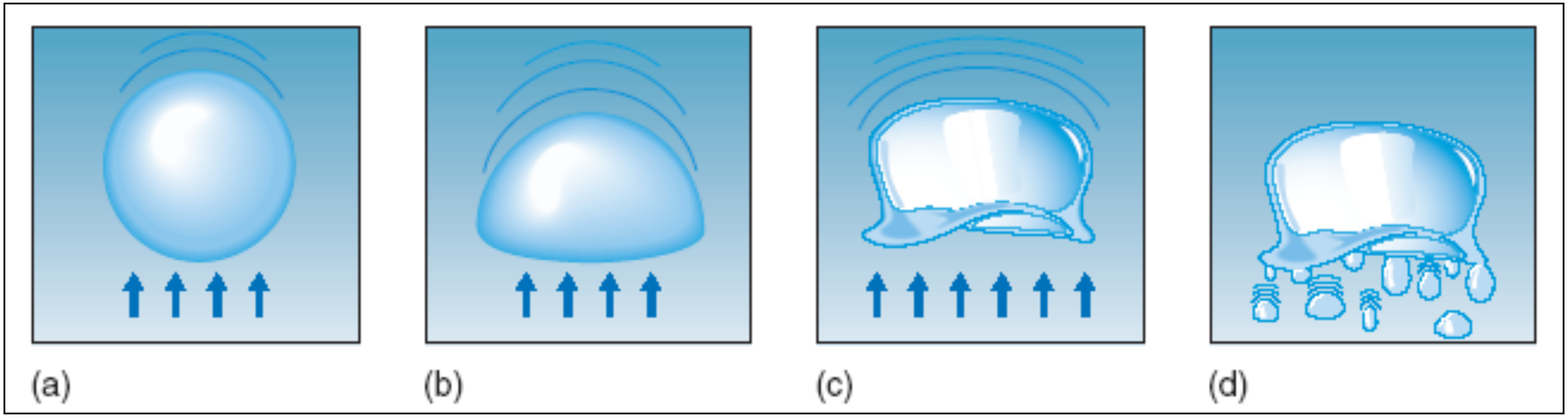
Updrafts and rain



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

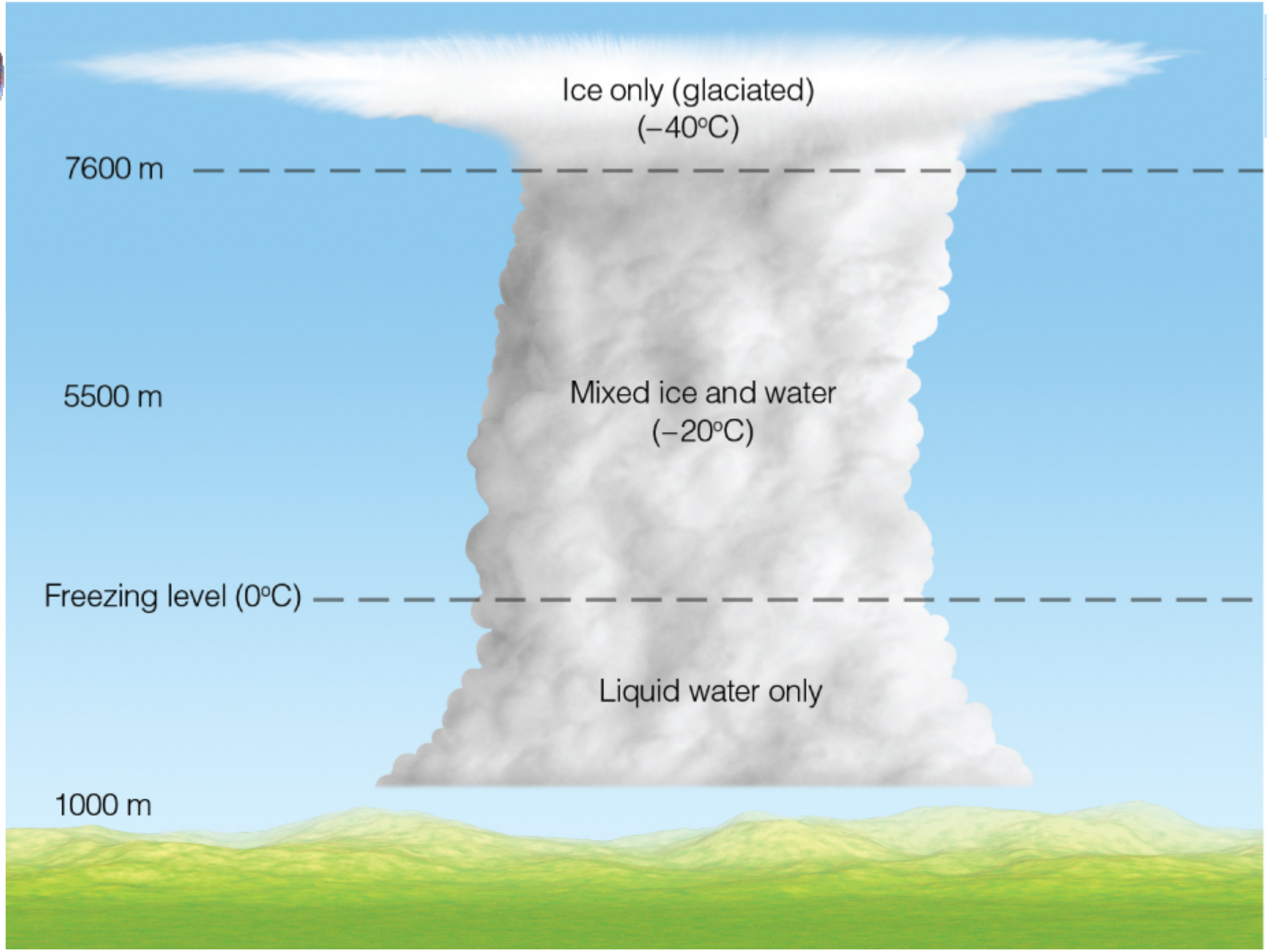
A&B: Figure 7-7

Ice nuclei

- Different materials than CCN
  - Rarer
  - Often clays

- 0 to -4°C: Clouds contain supercooled water

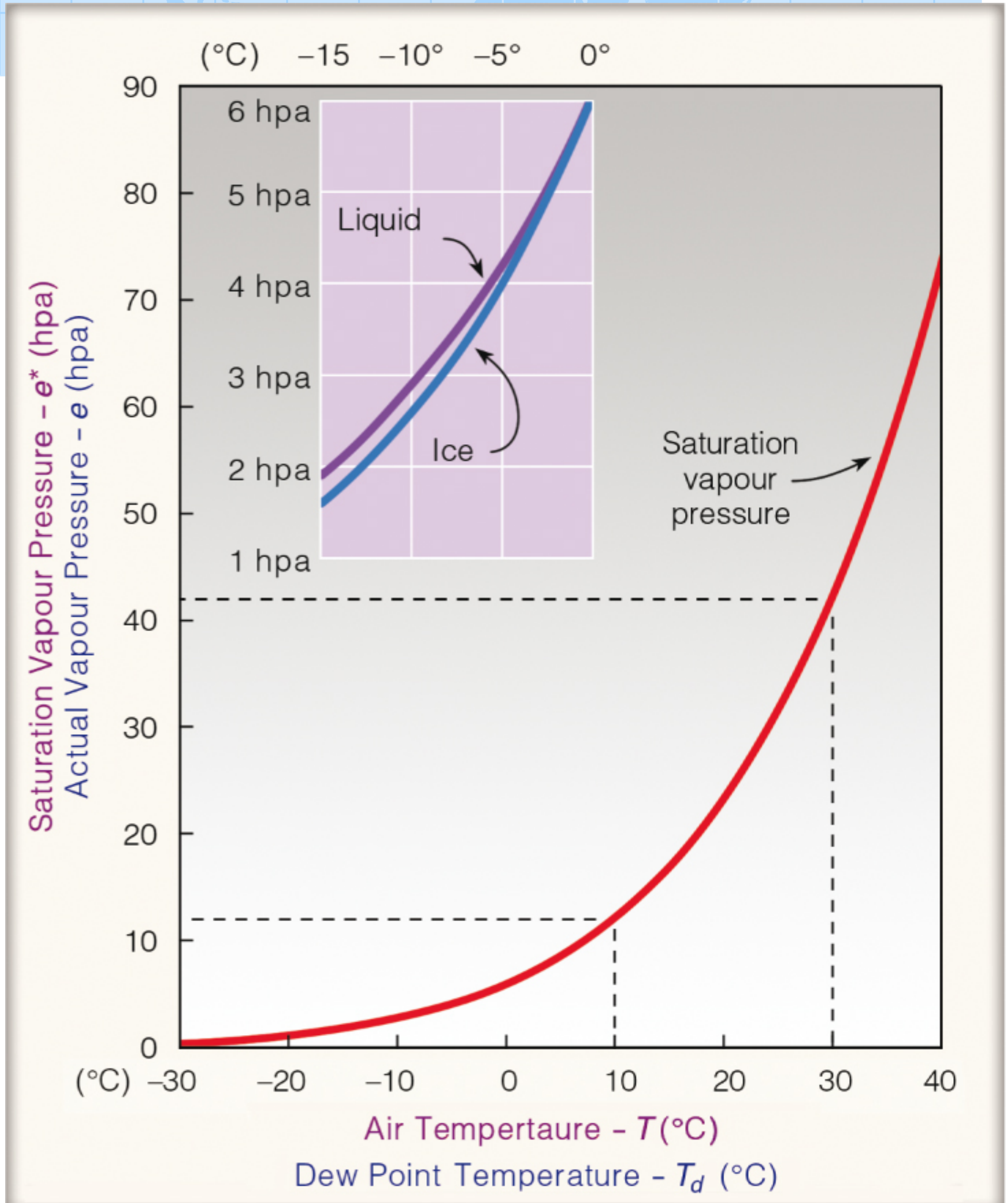
- -4 to -40°C: Clouds contain a mix of ice and supercooled water
  - Proportion depends on availability of nuclei



Ice and water in cumulonimbus clouds

Ahrens: Fig. 7.7

Saturation vapour pressure



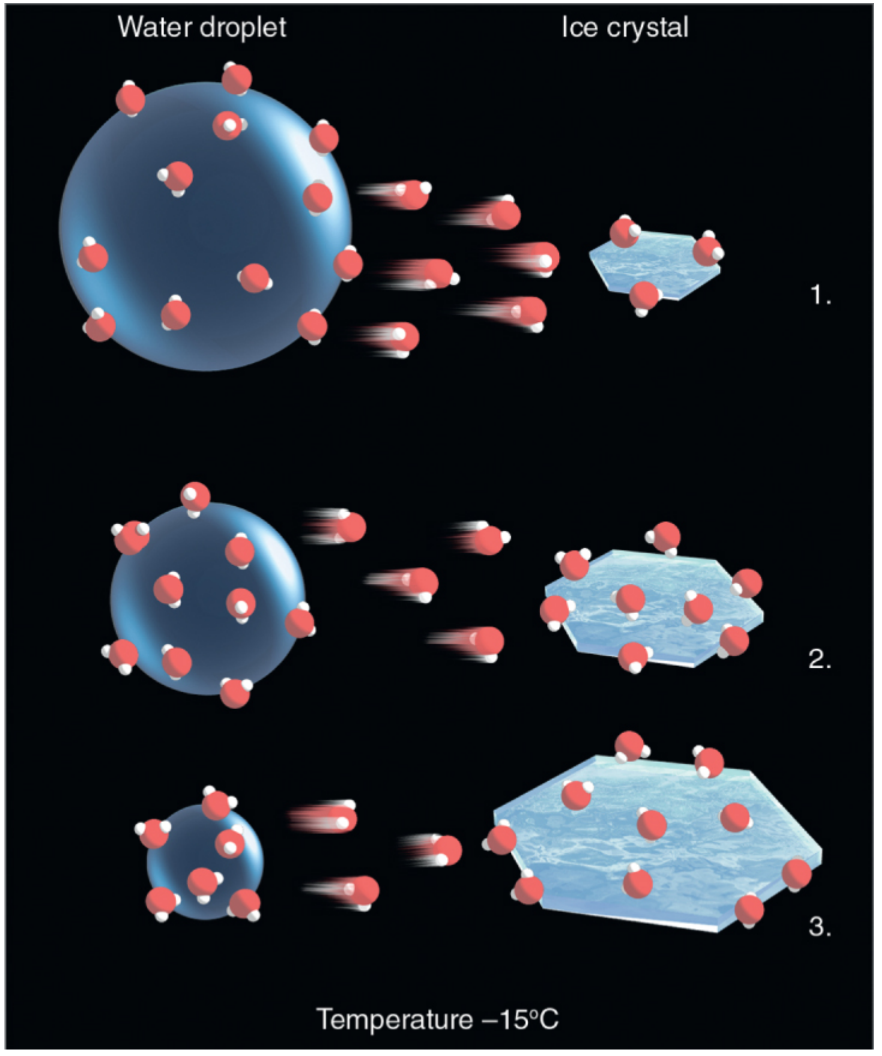
Ahrens: Fig 4.10

Bergeron process for ice crystals

- Ice has a lower saturation vapour pressure than water

- Net evaporation from water
- Net deposition to ice

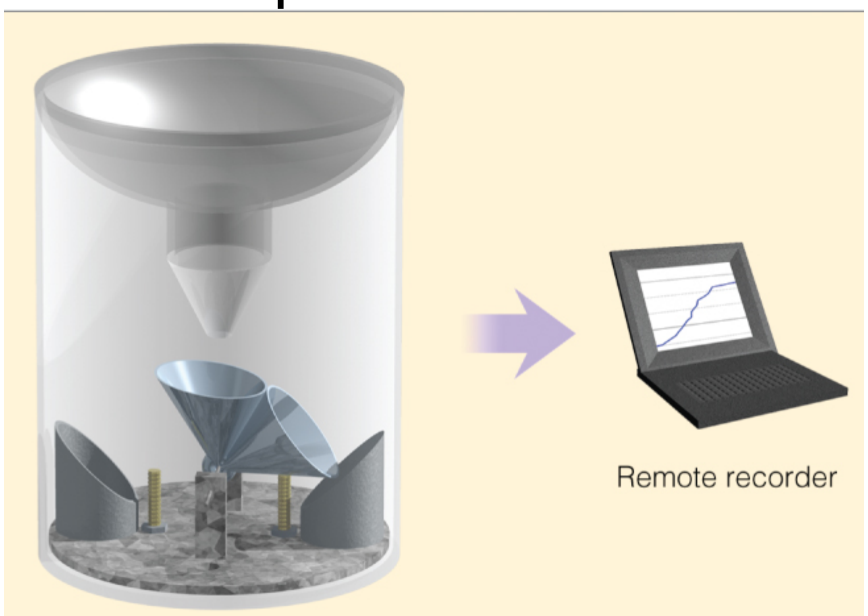
- Ice crystals grow while supercooled water droplets shrink



Ahrens: Fig. 7.10

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

Next Lecture

- Finish Precipitation

Midterm Review

GEOG/ENST 2331 – Lecture 12

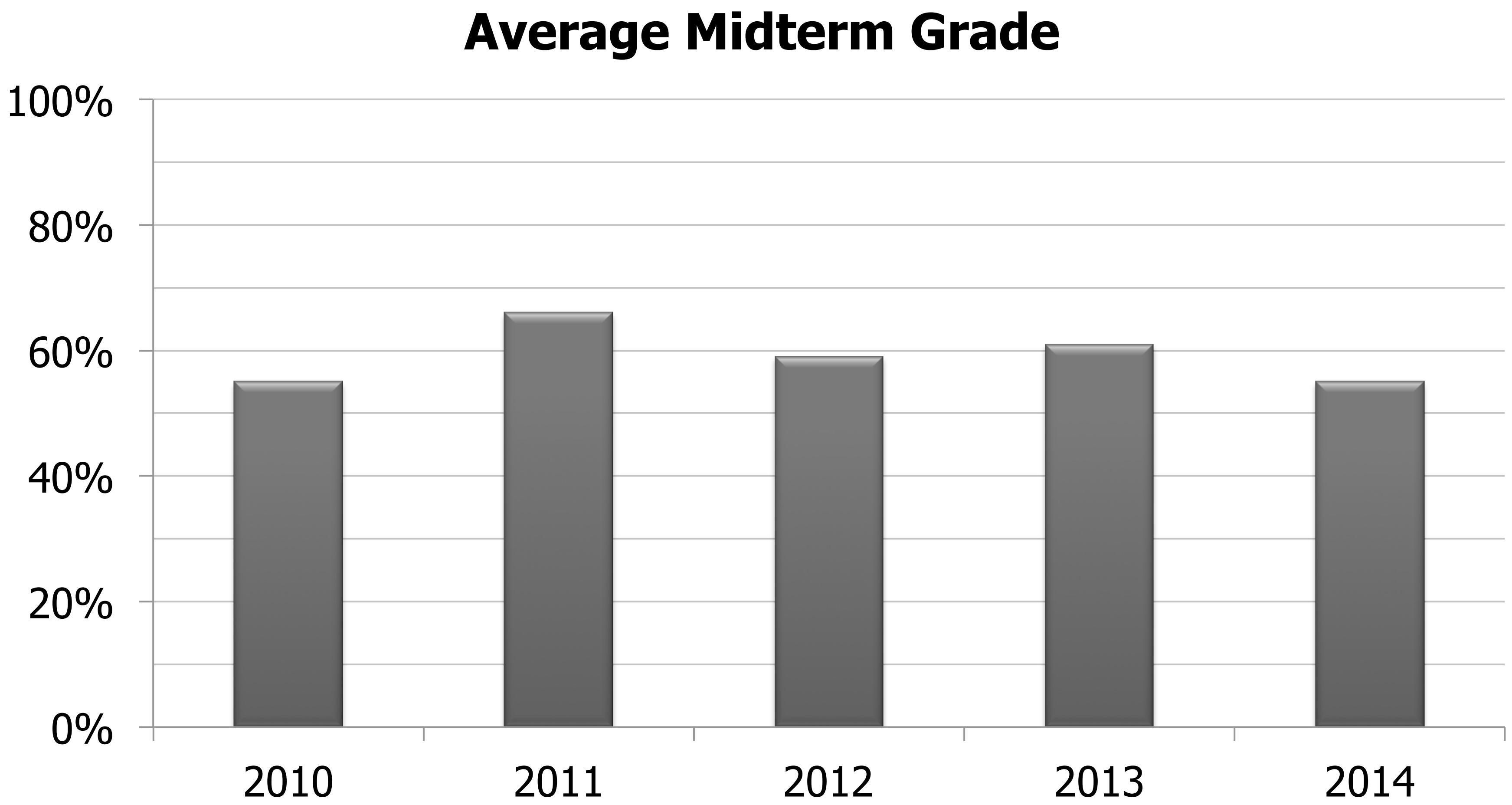
Ahrens et al., Chapters 1-8

Labs 1-3

Midterm

- Wednesday:
  - 30 multiple choice, three short answer
  - Bring a pencil for Scantron cards
  - Bring a non-programmable calculator
  - If equations are necessary they will be provided
- Lab quiz next week
  - See manual

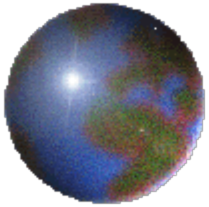
A caution



Average Midterm Grade
100%
80%
60%
40%
20%
0%
2010
2011
2012
2013
2014

Subject Review

- **The Atmosphere** (Chapter 1)
- **Solar Radiation** (Chapter 2)
- **Energy Balance and Temperature** (Chapter 3)
- **Atmospheric Pressure and Wind** (Chapter 8)
- **Atmospheric Moisture** (Chapter 4)
- **Cloud Development** (Chapters 5 and 6)
- **Precipitation** (Chapter 7)

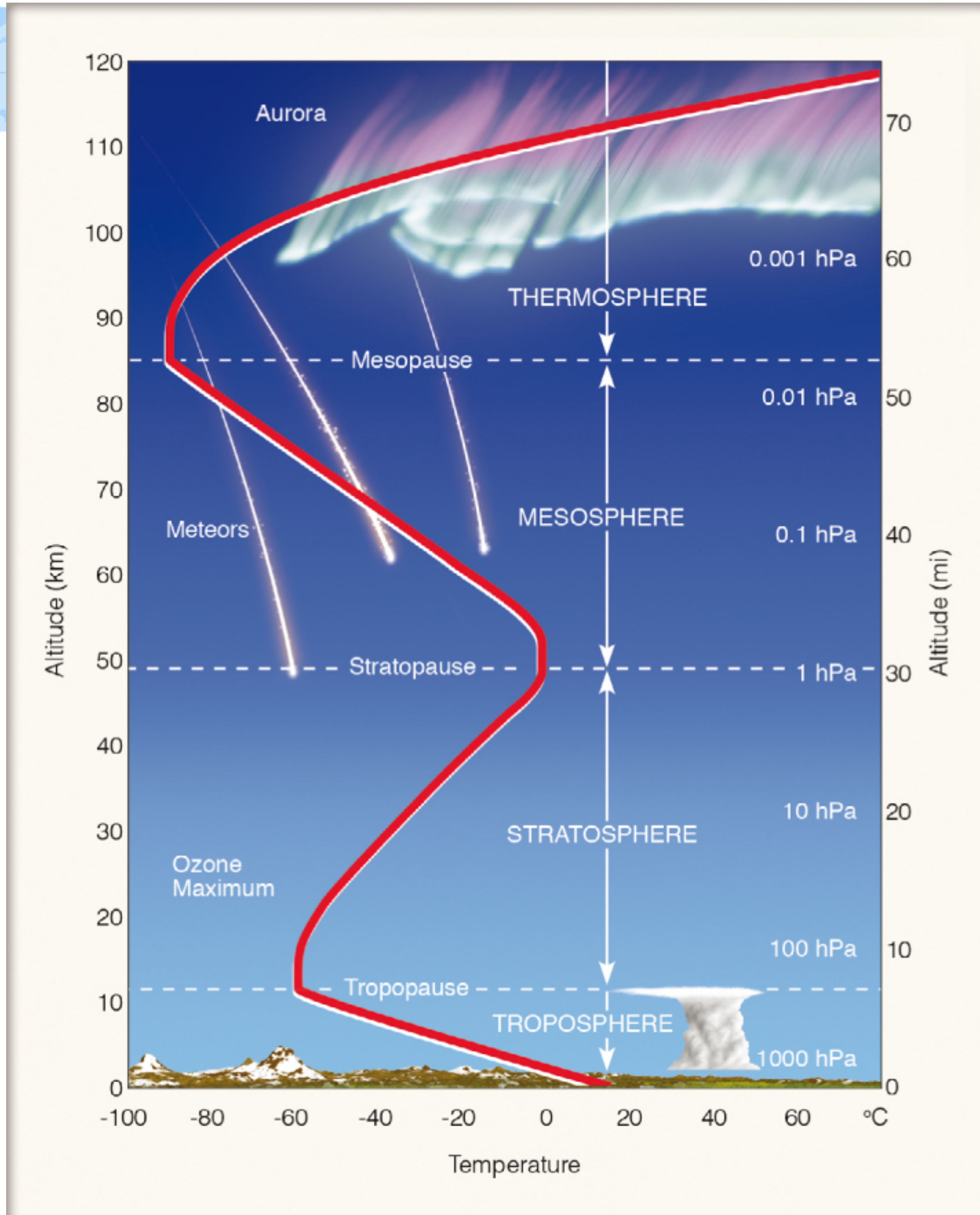


The Atmosphere

Structure and Composition

Chapter 1

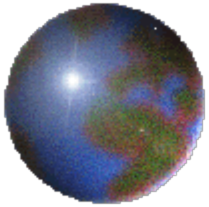
Thermal Layers of the Atmosphere



Ahrens: Fig. 1.11

Gases

- 'Permanent' Gases
  - Reservoir much larger than flux
  - Concentration stable over time
  - N_2, O_2, Ar
- 'Variable' Gases
  - Reservoir similar to or smaller than flux
  - Concentration can readily change
  - H_2O, CO_2, O_3



Solar Radiation

Energy and Radiation

Chapter 2

Radiation Laws

- Stefan-Boltzmann Law
  - $I = \varepsilon\sigma T^4$
- Wien's Law
  - $\lambda_m = 2897 / T$
- Kirchhoff's Law
  - $\varepsilon_\lambda = a_\lambda$

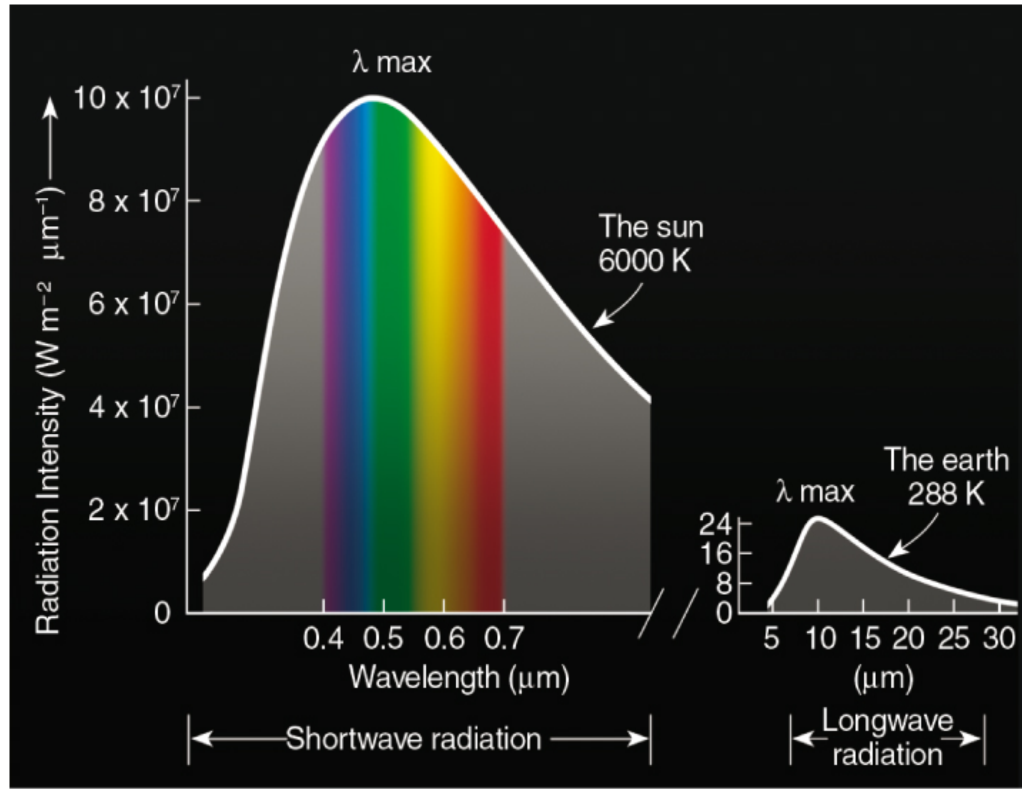
Wavelength of radiation (Wien)

Sun

$$\lambda_m = \frac{2897}{6000} \approx 0.50\ \mu\text{m}$$

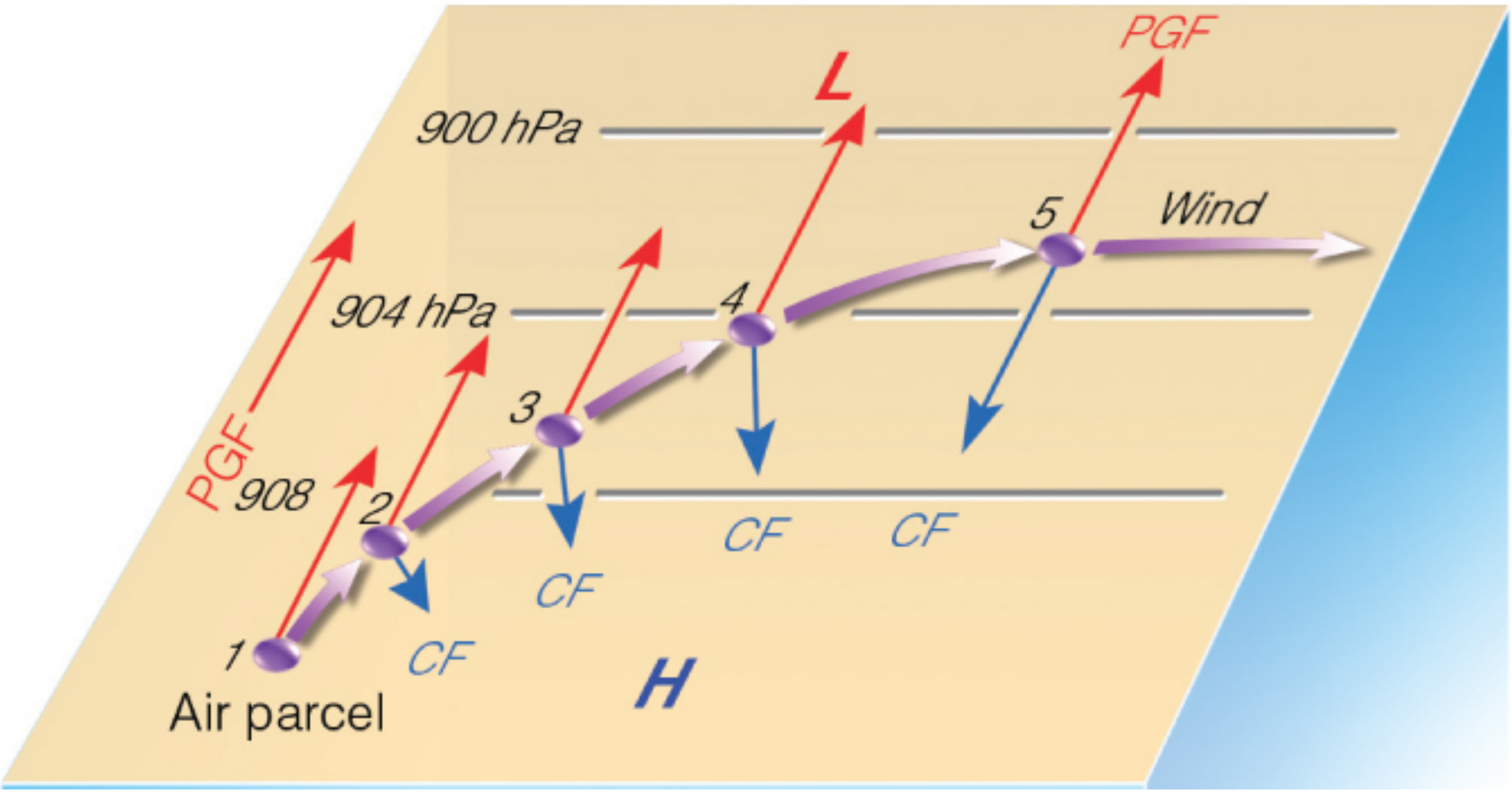
Earth

$$\lambda_m = \frac{2897}{288} \approx 10\ \mu\text{m}$$



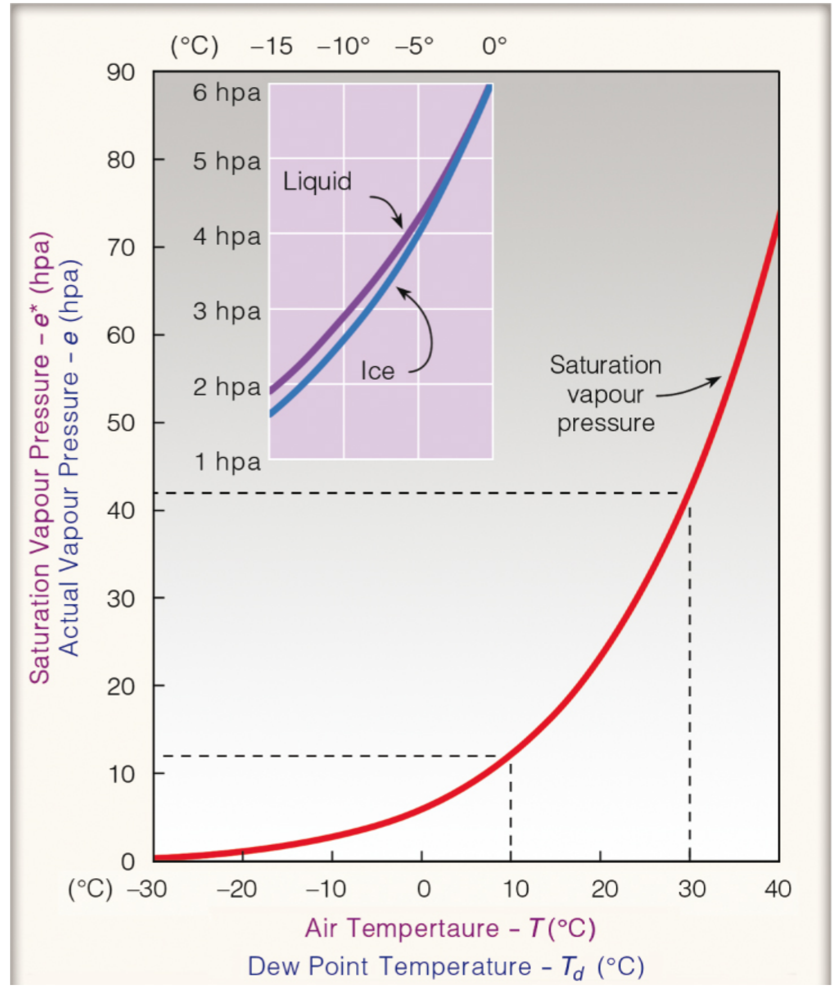
Ahrens, Fig. 2.9

Geostrophic Wind



Indices of Water Vapor Content

- Absolute Humidity
- Specific Humidity
  - Saturation specific humidity
- Vapour Pressure
  - Saturation vapour pressure
- Relative Humidity
- Dew Point



Cloud Development

Mechanisms that Lift Air

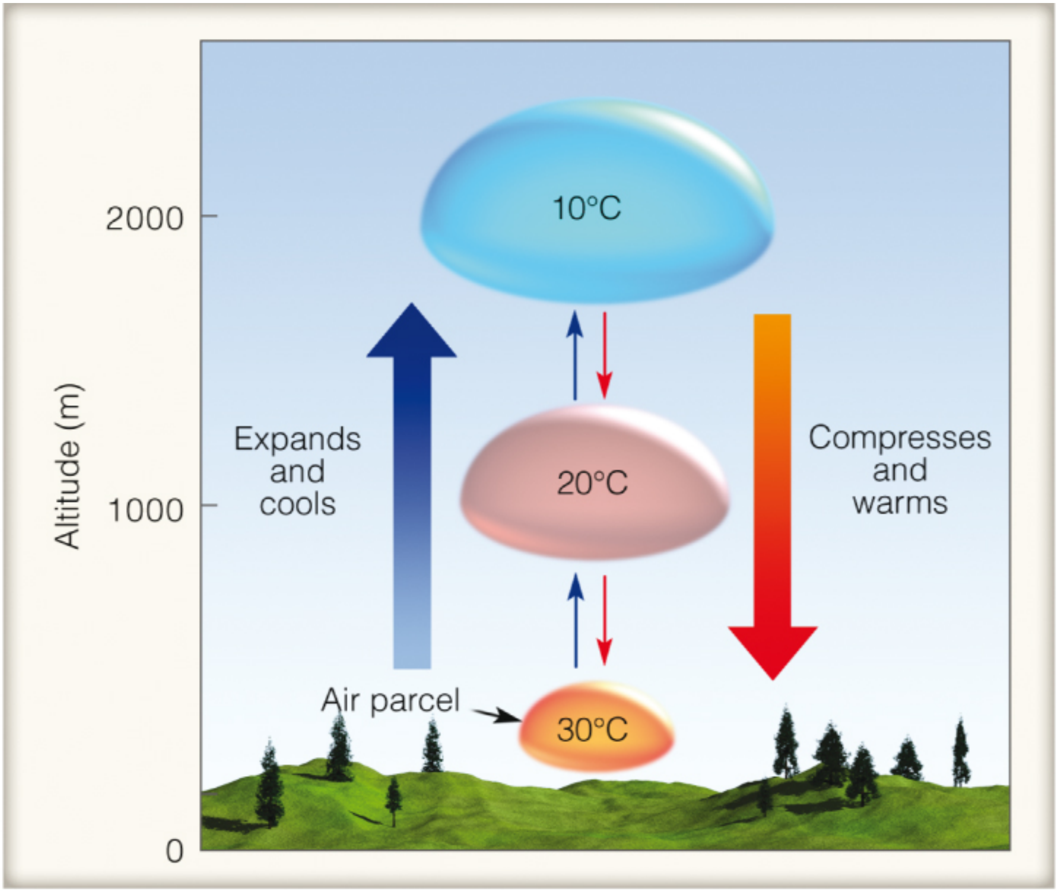
Stability and the Environmental Lapse Rate

Factors Influencing the Environmental Lapse Rate

Limitations on the Lifting of Unstable Air

Cloud Nomenclature

Chapters 5 and 6



Dry Adiabatic Lapse Rate (DALR)

Air warms or cools at 1°C / 100 m

Ahrens: Active Fig. 6.2

Precipitation

- Collision-coalescence
- Bergeron process
- Ice pellets and freezing rain
- Hail

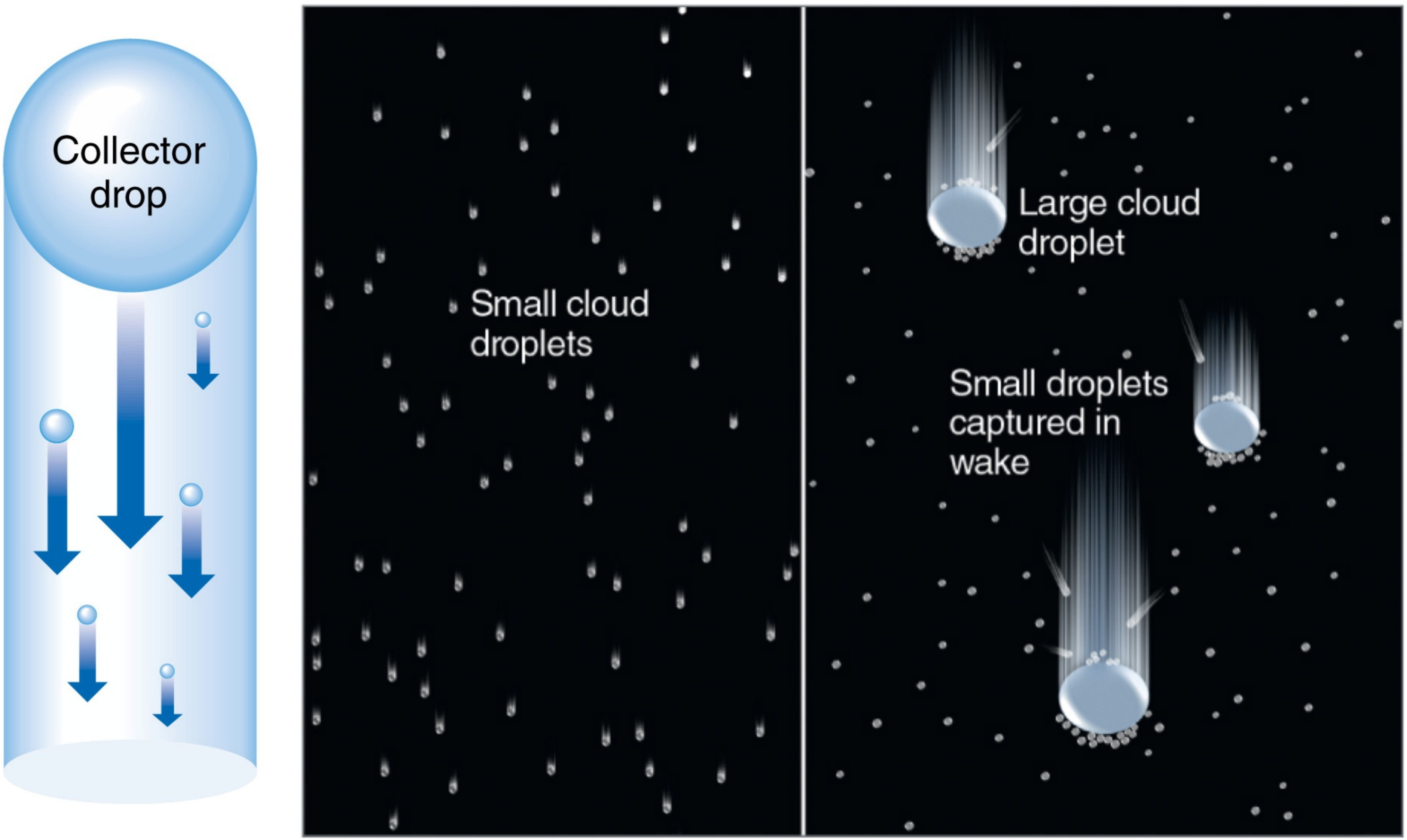
Cloud condensation nuclei

- Aerosols particles that water can condense around
  - *Hygroscopic* material aids droplet formation
  - Solution effect reduces rate of evaporation

- If no CCN are available:
  - RH can exceed 100% - *supersaturation*
  - Liquid molecules evaporate again before they can collect together and form droplets

Collision-coalescence

Ahrens: Fig. 7.5

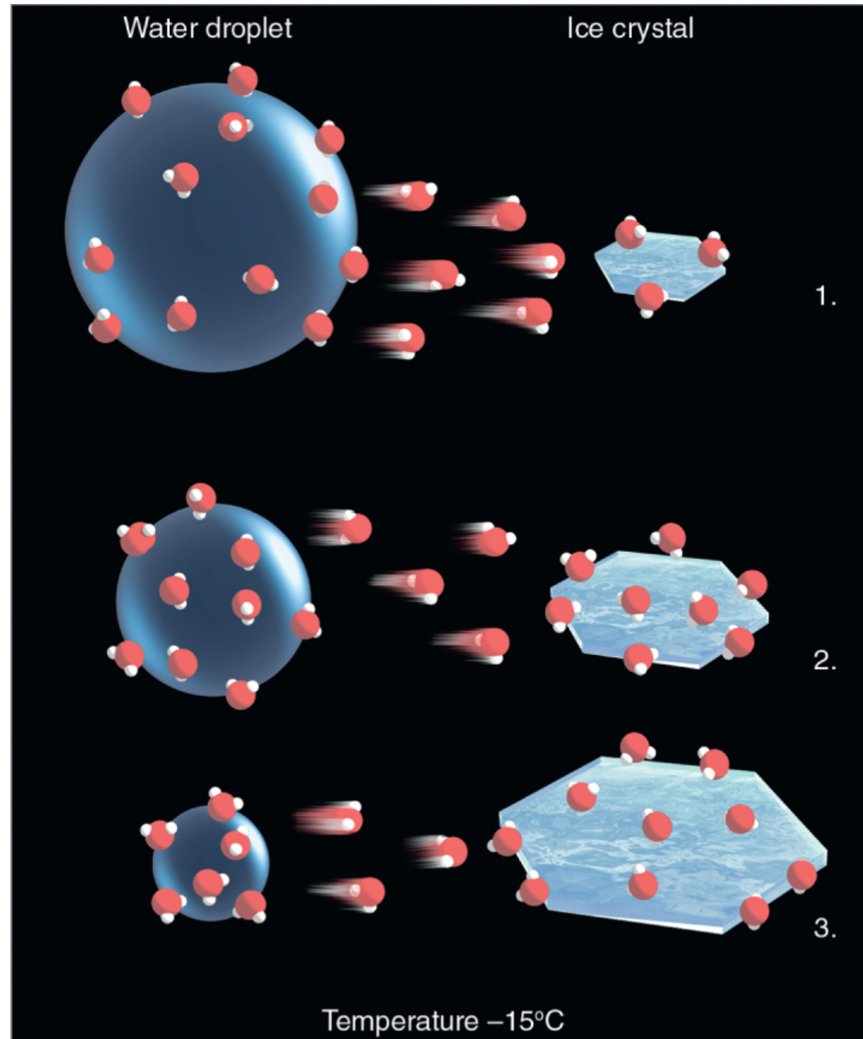


Bergeron process for ice crystals

- 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

See you on Wednesday

I will do my best to answer questions received by noon Tuesday