Cloud Formation
Brief review for Midterm

GEOG/ENST 2331 – Lecture 10

Ahrens et al. Chapters 5 & 6

Recent lectures and labs

- Lifting mechanisms
  - Orographic lifting
  - Frontal lifting
  - Convergence
  - Convection
- Atmospheric stability

Cloud formation

- **First a bit more on atmospheric stability**
  - Cloud formation requires rising air, i.e. instability must be present
  - How does the atmosphere evolve from stable to unstable?
  - **Surface warming**
  - **Advection**
  - **Lifting**
- Condensation
- Types of clouds

Causes of Instability

- DALR is 10°C/km and SALR is 6°C/km
  - Conditional stability when ELR > 6°C/km
  - Absolute instability when ELR > 10°C/km

- Two mechanisms for increasing the lapse rate:
  1. Temperature change
     a. Heat the surface air
     b. Cool the upper air
  2. Potential instability
     - Lifting of a layer of air

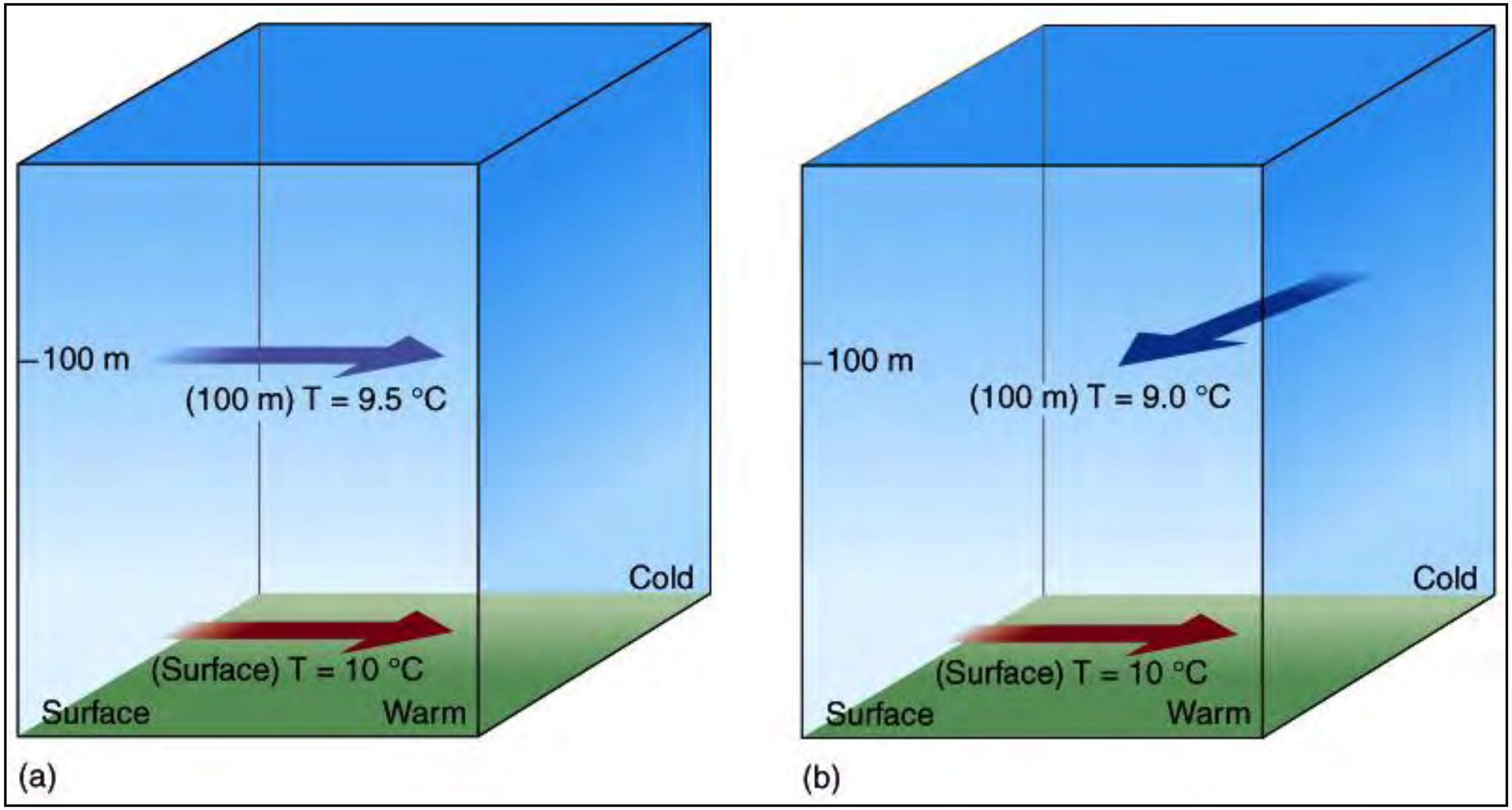
1a Surface Warming

	7°C/km		12°C/km
1000 m	10°C	→	10°C
0 m	17°C	→	22°C

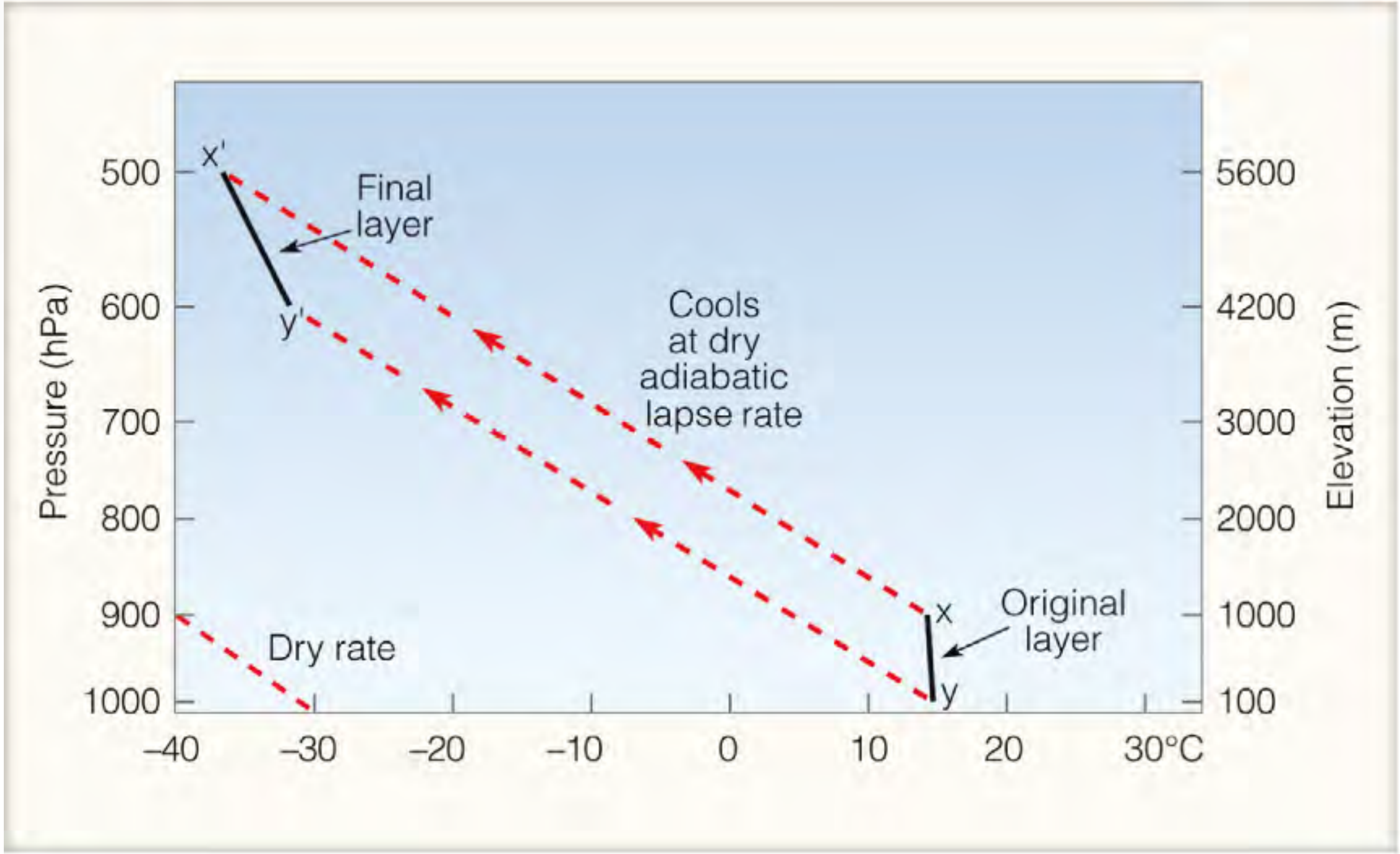
1b Cooling aloft

	7°C/km		12°C/km
1000 m	10°C	⇨	5°C
0 m	17°C	⇨	17°C

Example: Cool air advection



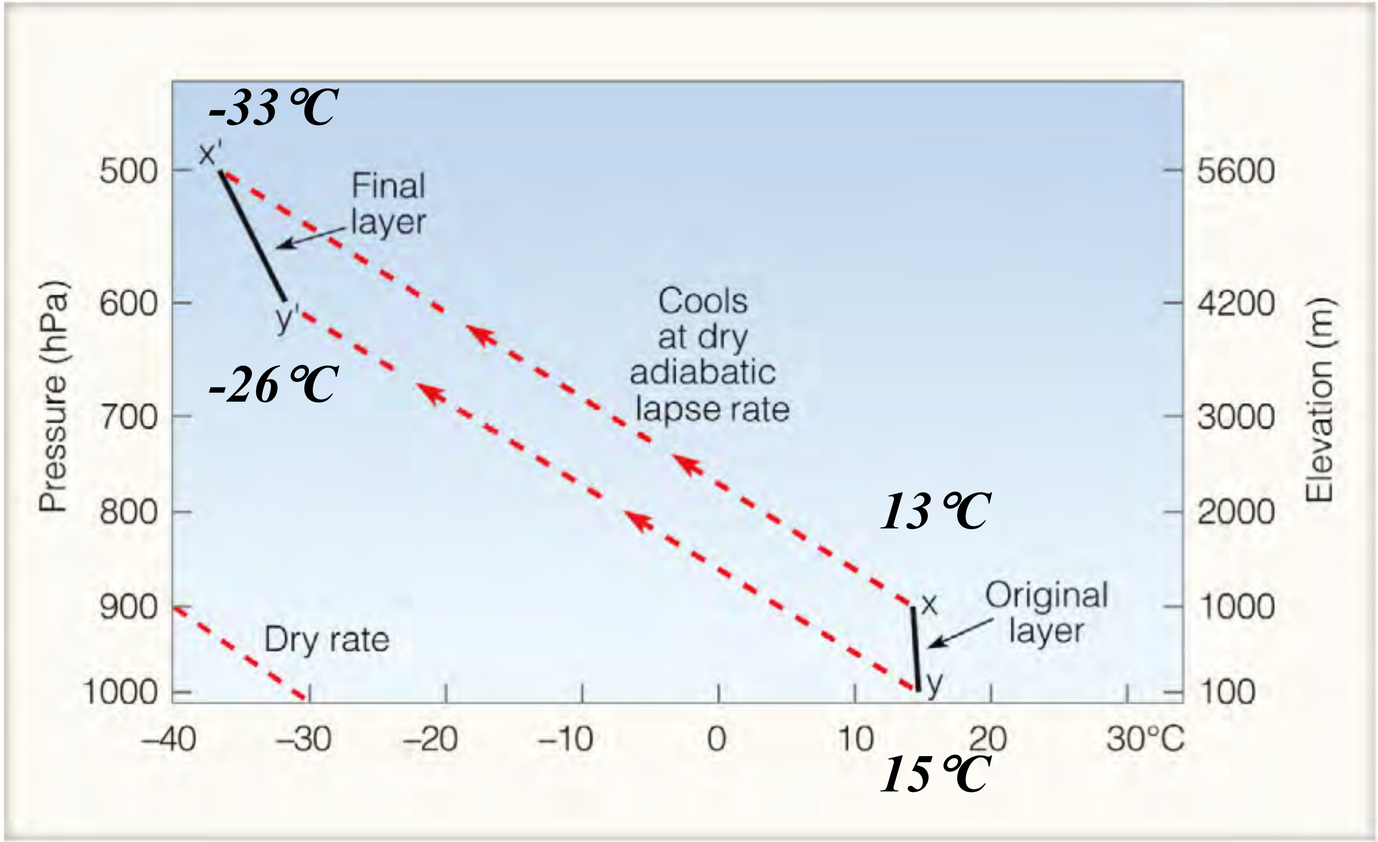
2a Potential instability



X'-y' is less stable than x-y

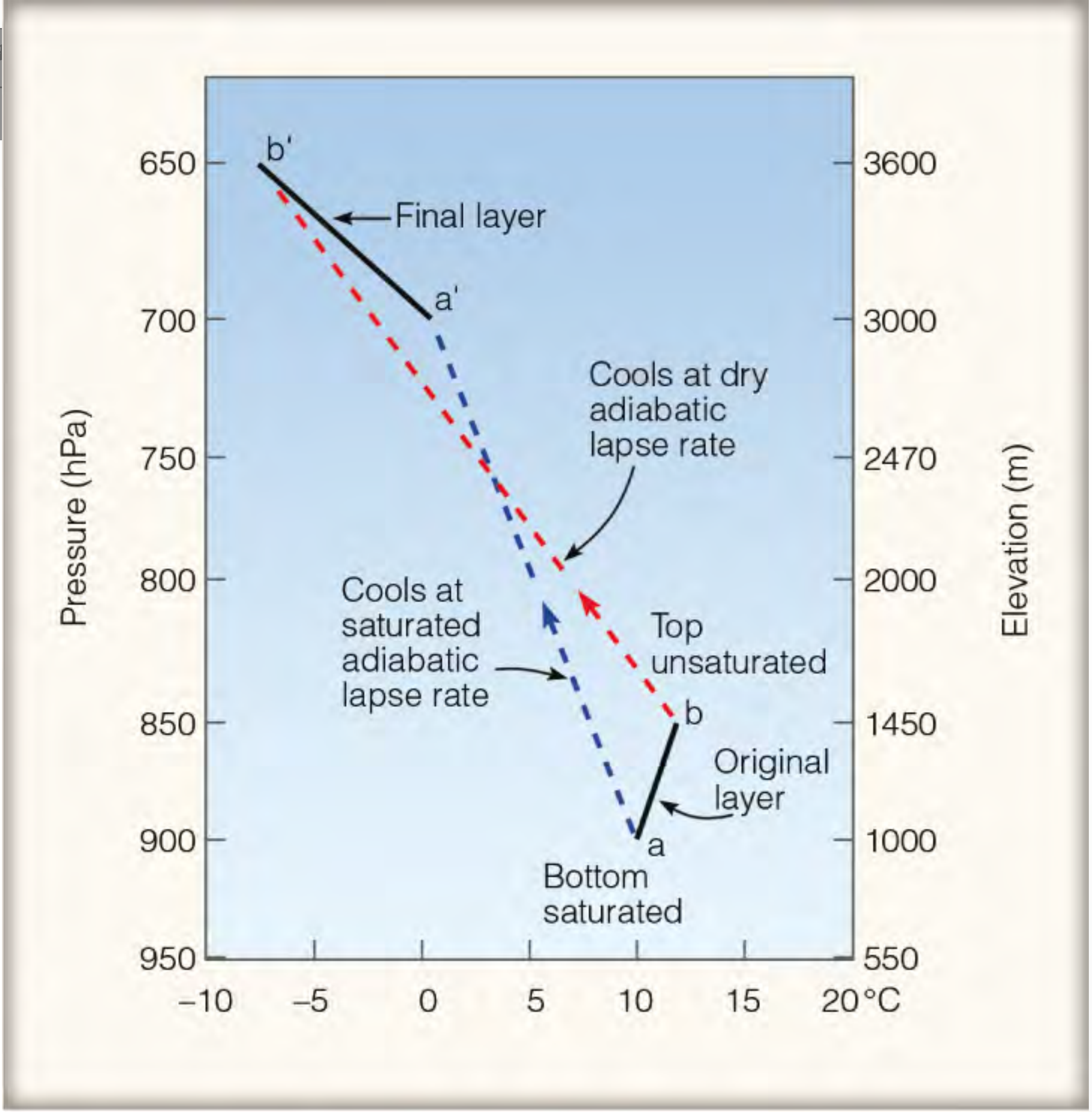
Expansion

- Initial lapse rate: 2.2°C / km (absolutely stable)
- Final lapse rate: 7°C / 1.4 km = 5°C / km (close to conditionally unstable)
- Layer of air expands, so top rises farther and cools more than bottom



Ahrens: Fig. 6.13

2b Potential Instability



Ahrens: Fig. 6.14

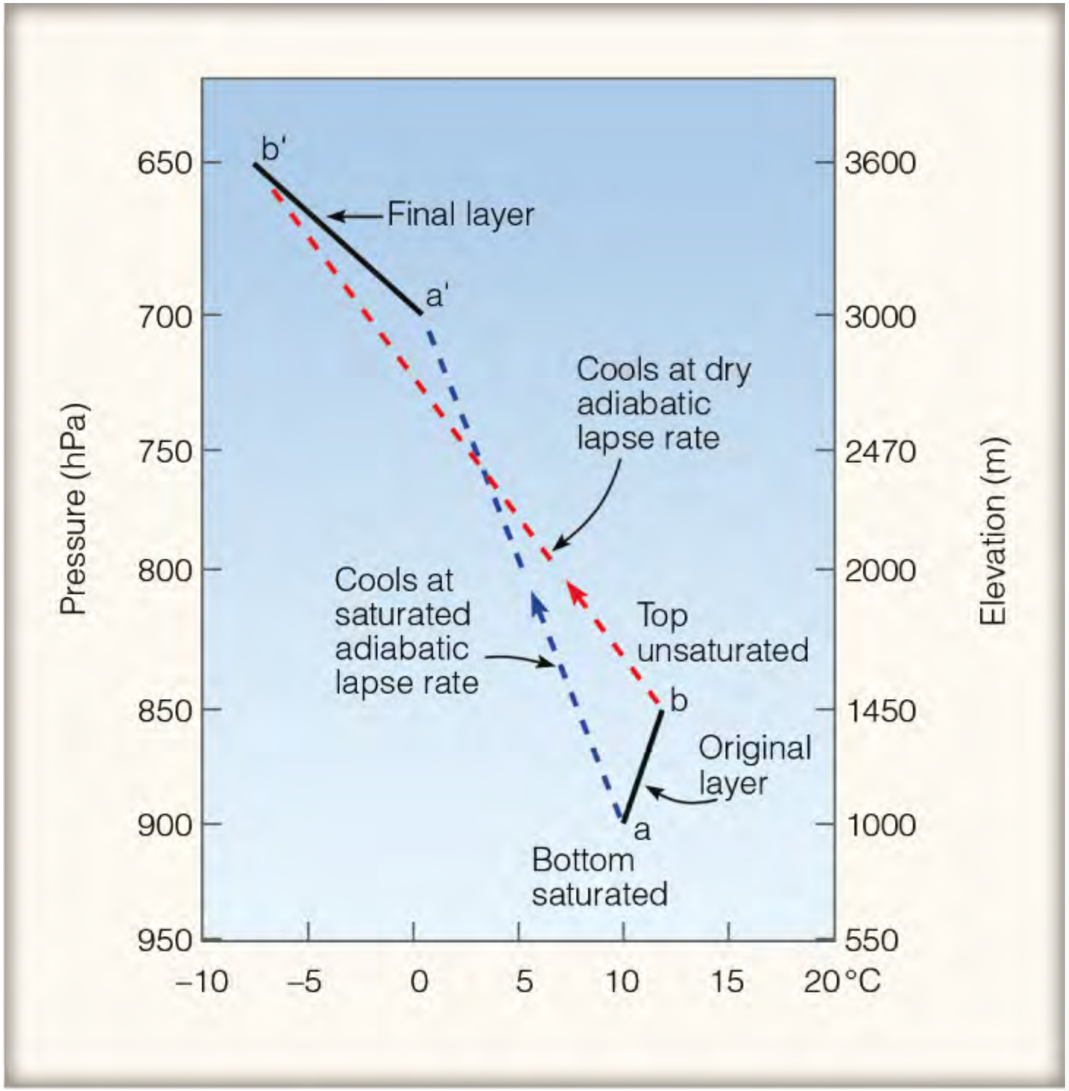
Potential Instability

Top of layer cools at DALR

Bottom cools at SALR

Initially, -3°C over 450 m =
-6.7°C / km

Finally, 9°C over 600 m =
15°C / km

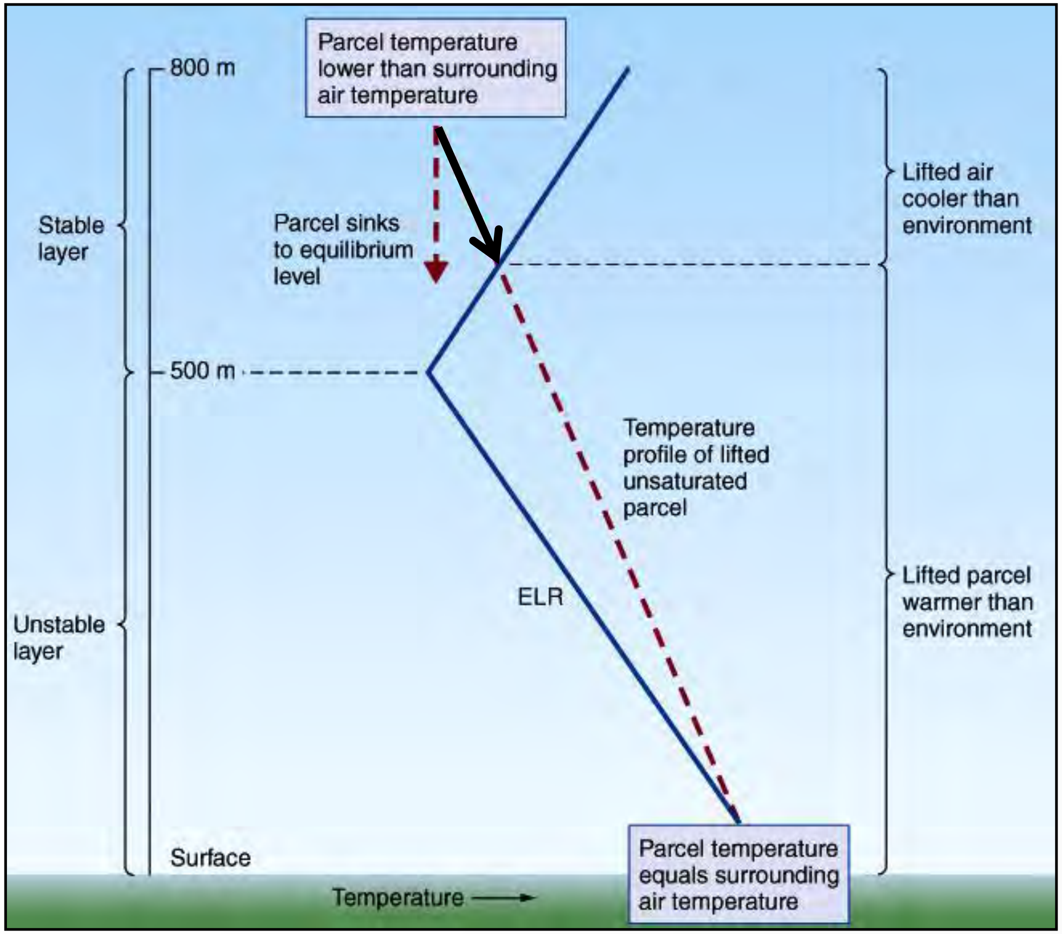


Entrainment

- Rising parcel creates turbulence
  - Small eddy circulations
- Mixes air from the environment into the parcel
  - Very likely unsaturated
  - Evaporating water cools the parcel back down
- Most evident at the cloud boundaries

Stable air

- Eventually a rising parcel will encounter stable air
- A "lid"
- Stops rising
  - Lag while *T* catches up
  - May continue briefly due to momentum

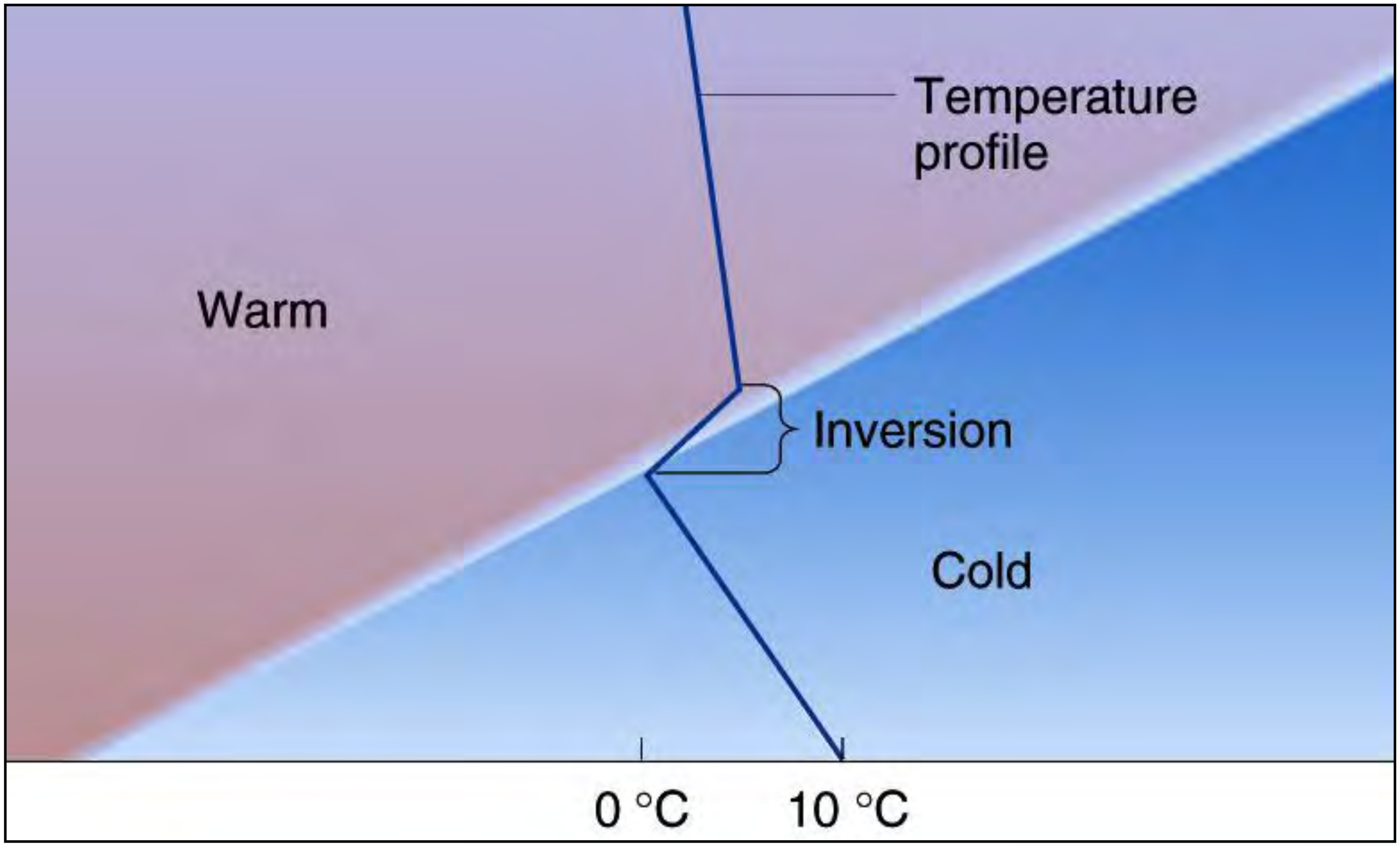


A&B: Figure 6-12

Radiation inversions

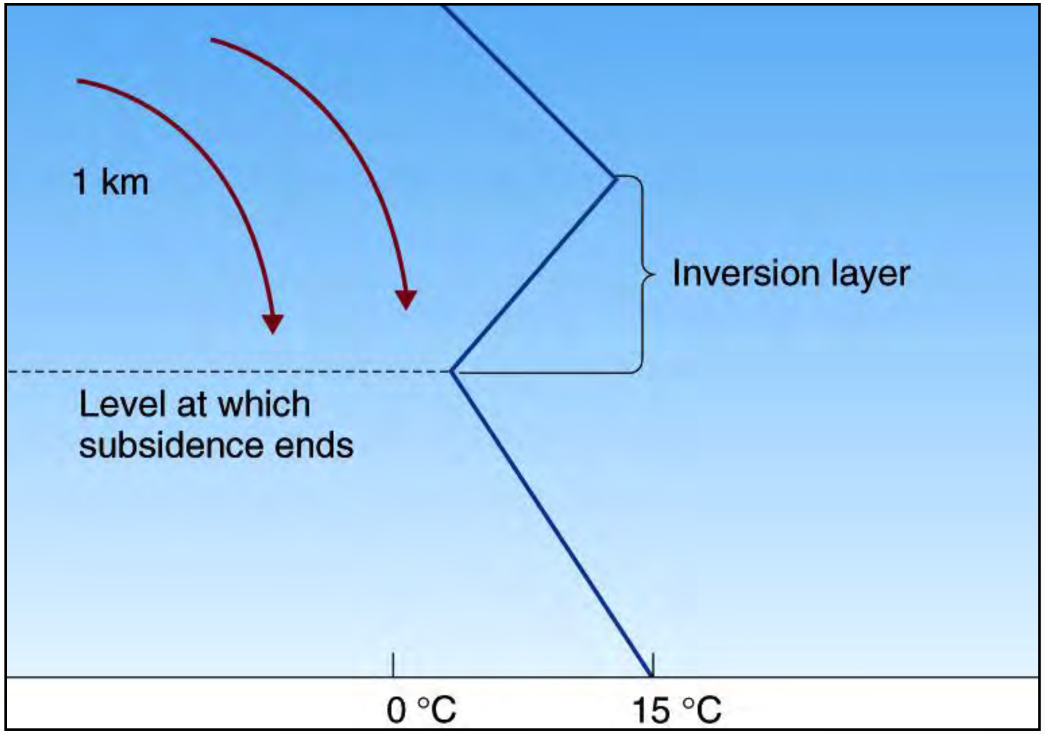
- Surface cools very quickly at night
  - Becomes colder than air above it
  - Temperature profile is inverted

Frontal inversions

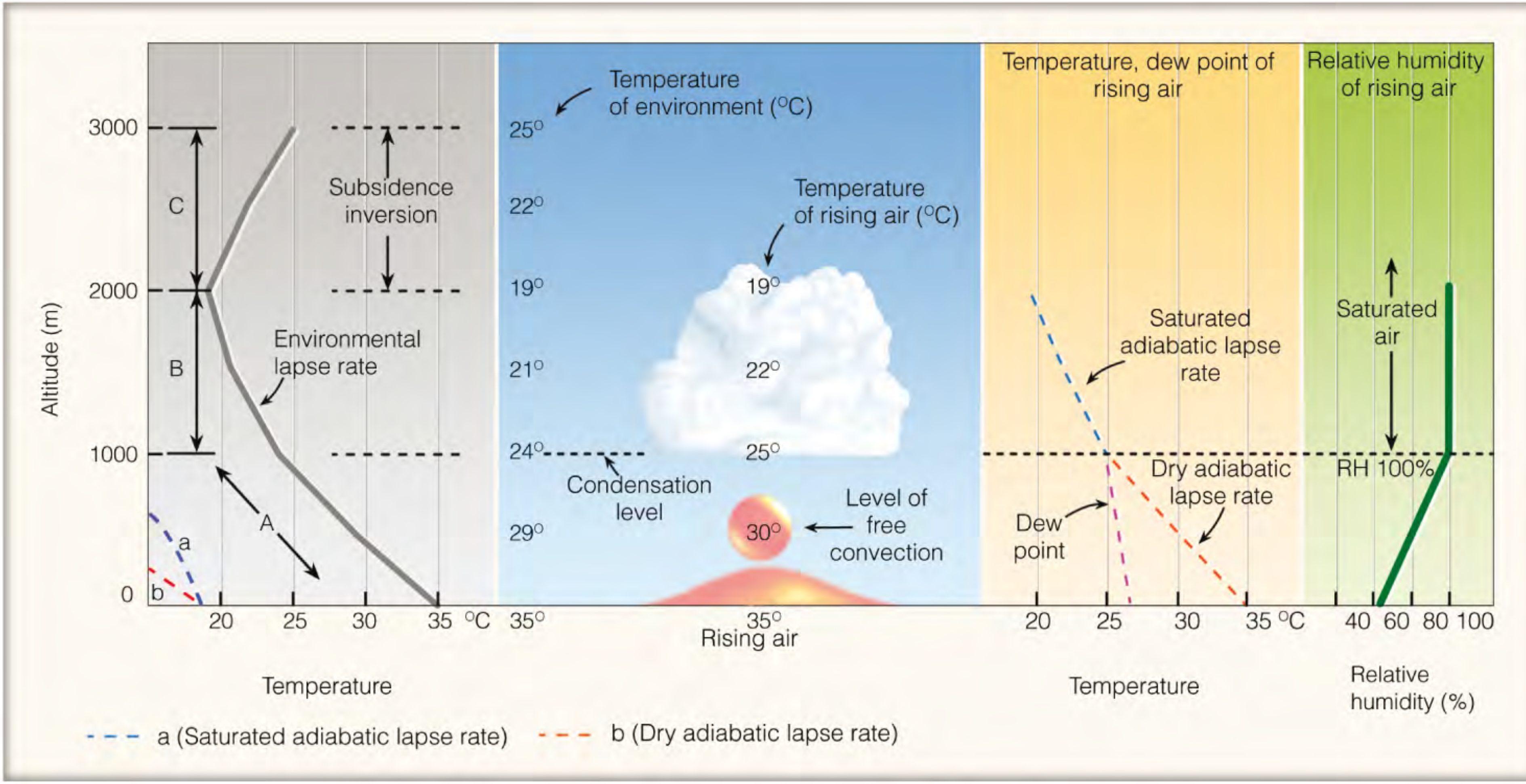


Subsidence inversion

- Warm air is less dense
- Lee side wind may be unable to push aside cold air



Development of a cumulus cloud



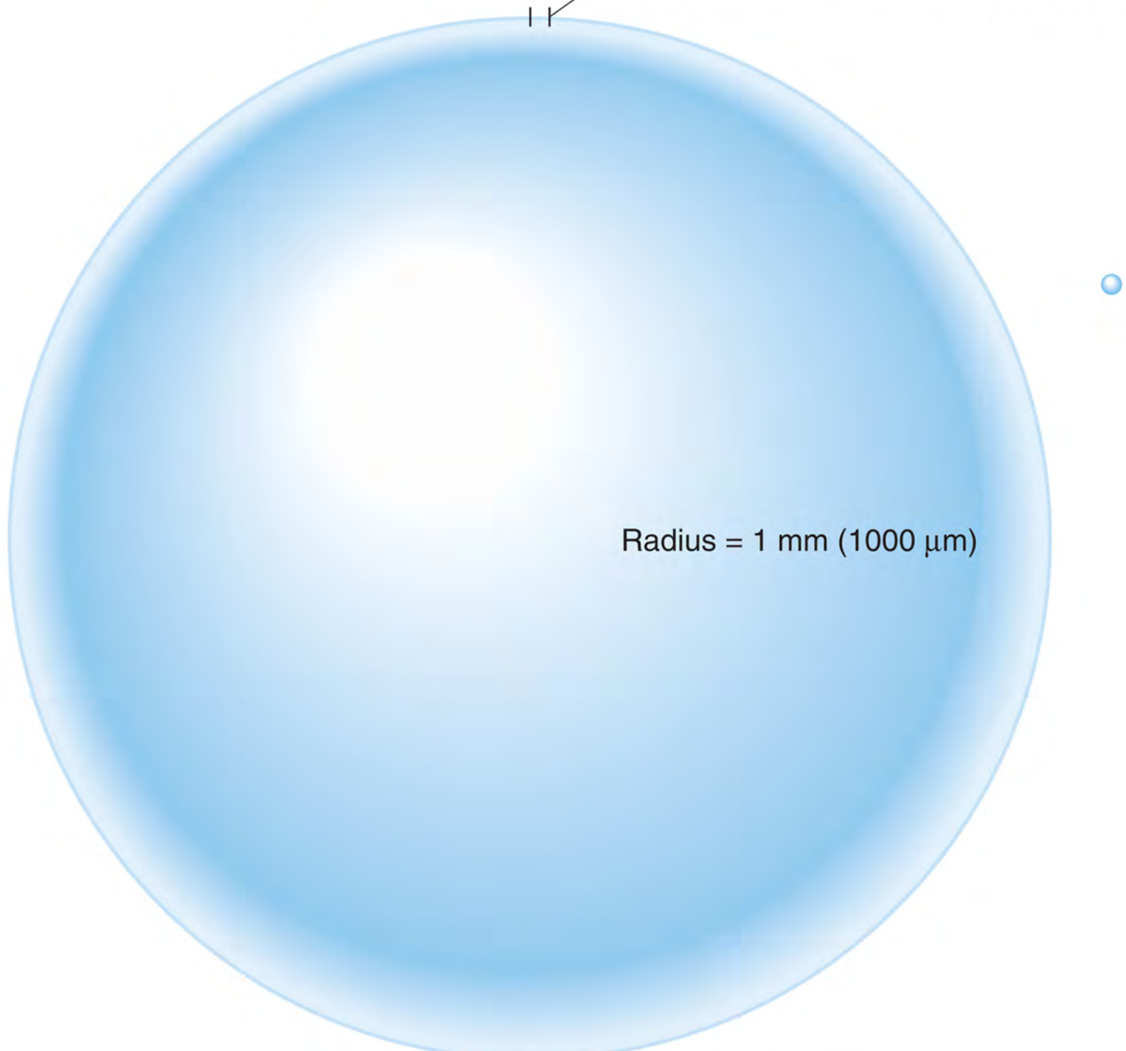
Ahrens: Active Fig. 6.18

Condensation

- Not as easy as it sounds
- Molecules must find each other and bond together
- Easily separated again by collisions with other air molecules

Curvature

High curvature means water molecules are more exposed to air molecules



A&B: Figure 5-11

Cloud condensation nuclei (CCN)

- Solid particles provide a surface to bond onto
  - Initially; eventually they dissolve

- Solution effect
  - Molecules of the dissolved substance don't evaporate
  - Some of the water molecules along the surface are replaced
  - Rate of evaporation is reduced

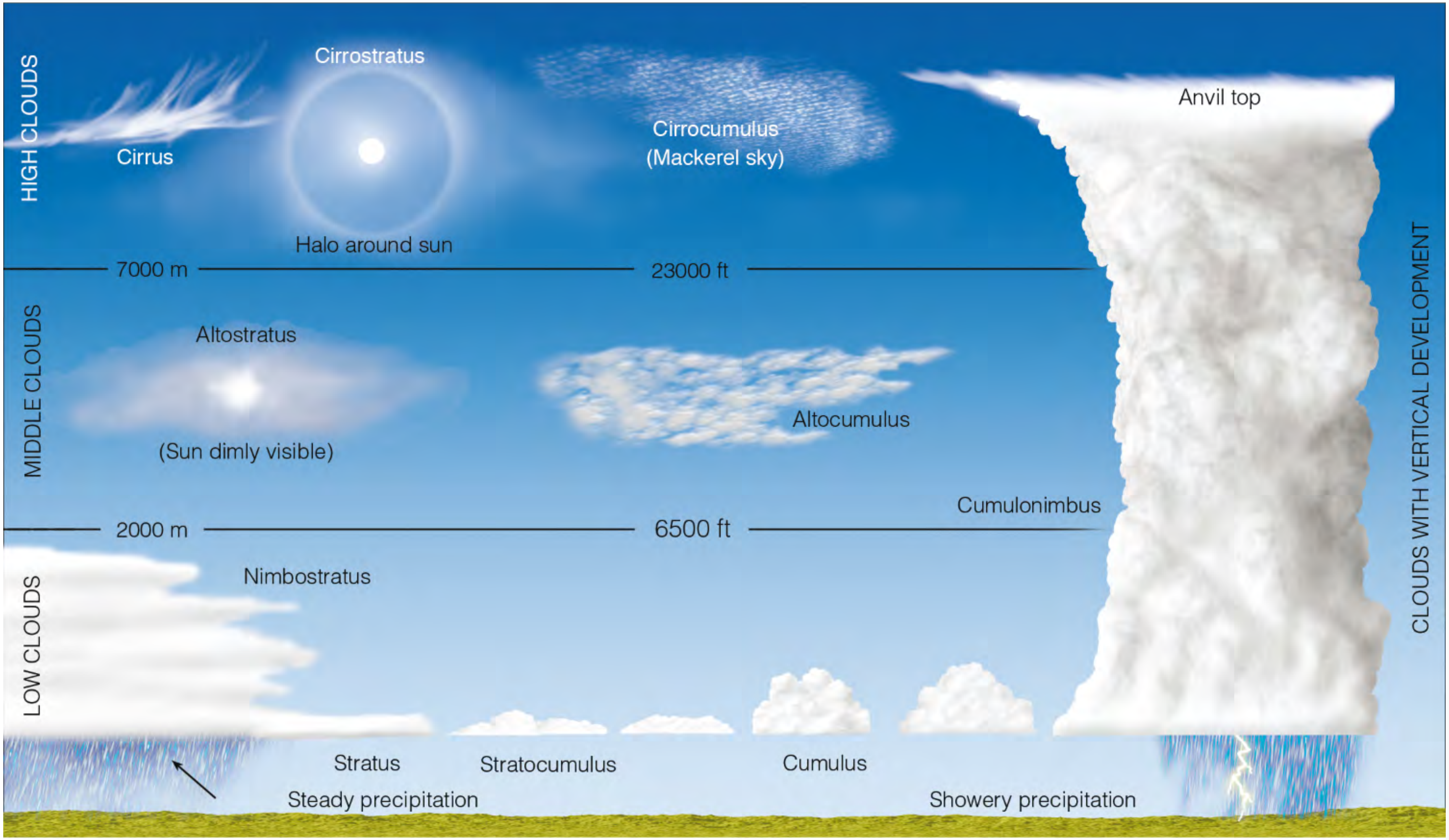
Cloud condensation nuclei

- *Hygroscopic* material aids droplet formation
  - CCN are roughly 0.2 μm
  - Cloud droplets are roughly 20 μm or 0.02 mm
- *Supersaturation* occurs if no CCN are available
  - RH can exceed 100% - *supersaturation*
  - Liquid molecules evaporate again before they can collect together and form droplets

Cloud Nomenclature

- Stratus, strato-
  - Layer clouds
- Cumulus, cumulo-
  - ‘puffy’ clouds
- Alto
  - Middle clouds (2000 – 7000 m)
- Cirrus, cirro-
  - High clouds (above 7000 m)
- Nimbus, nimbo-
  - Rain clouds

Cloud types



Ahrens: Fig. 5.27

Cloud Nomenclature

Strato (layered)

- Stratus
- Nimbostratus
- Altostratus
- Cirrostratus

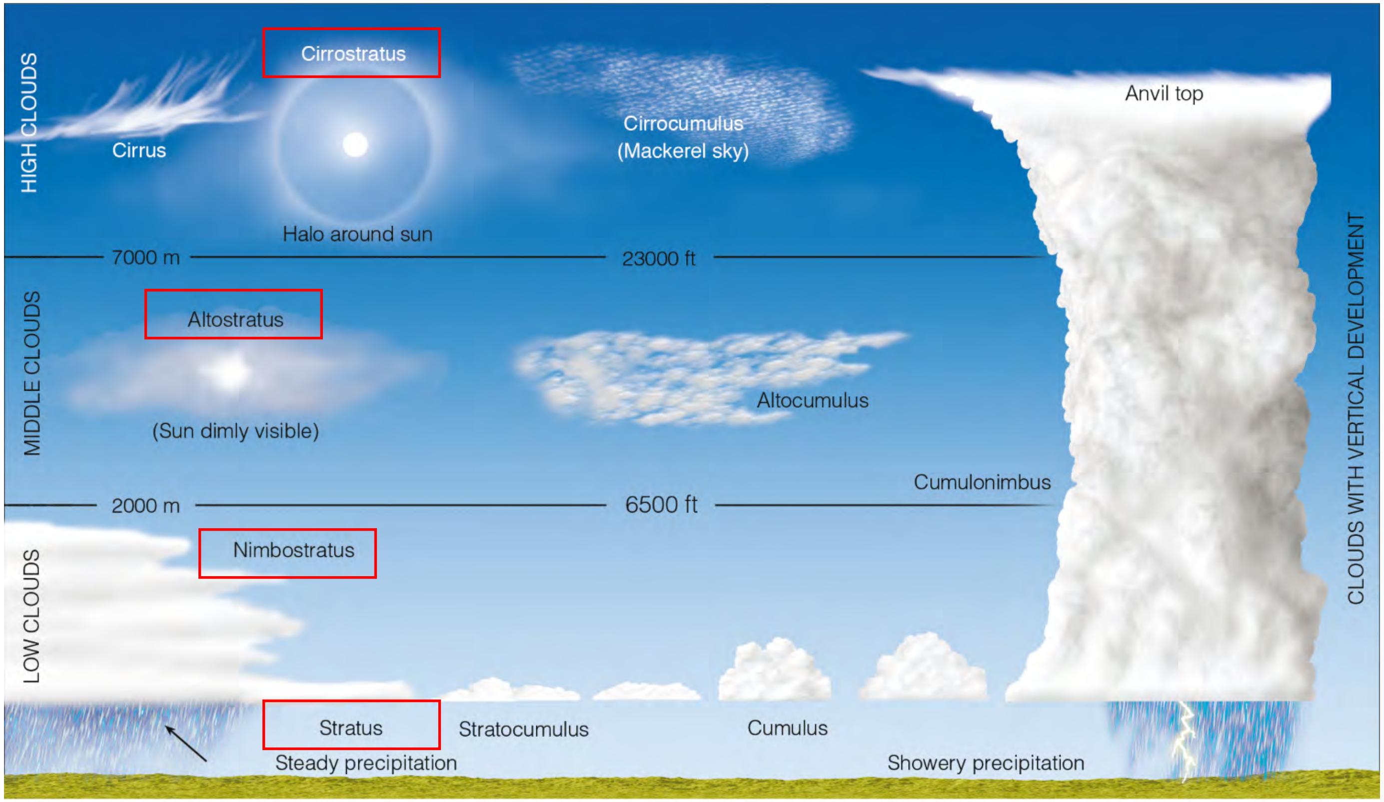
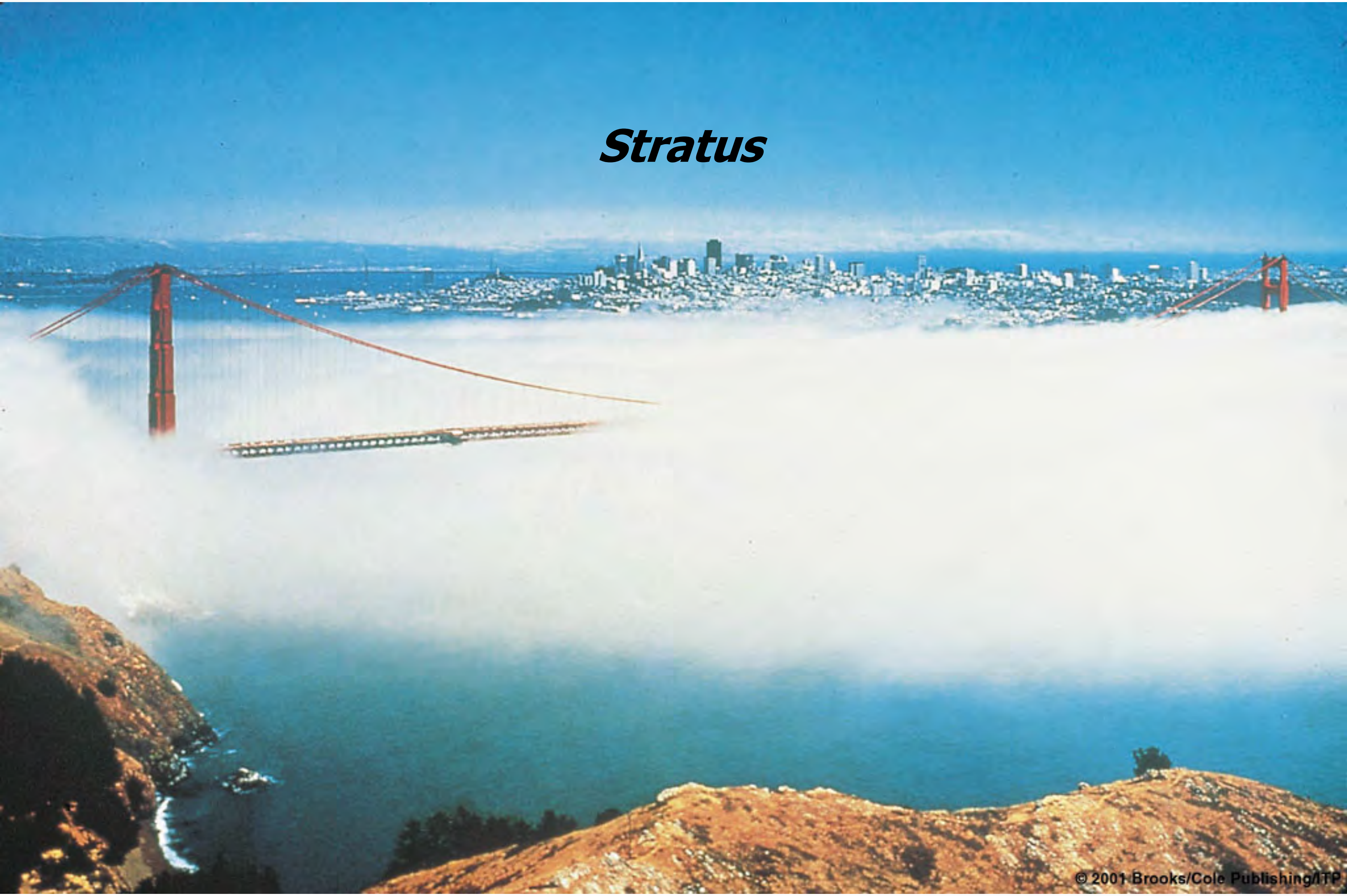


FIGURE 5.27 A generalized illustration of basic cloud types (genera) based on height above Earth's surface and the extent of vertical development.

Stratus



Altostratus

Cirrostratus

Cloud Nomenclature

Cumulo (heaped)

- Cumulus
- Stratocumulus
- Altocumulus
- Cirrocumulus
- Cumulonimbus

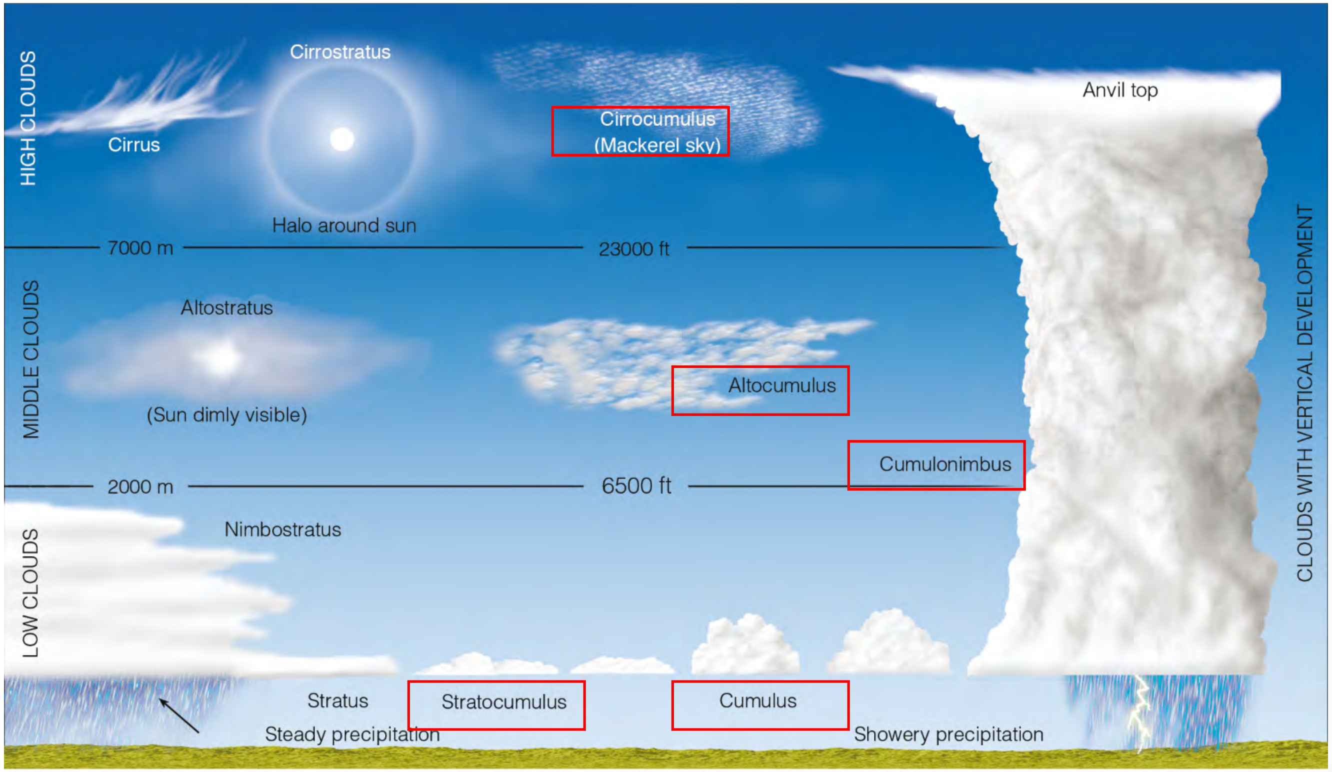
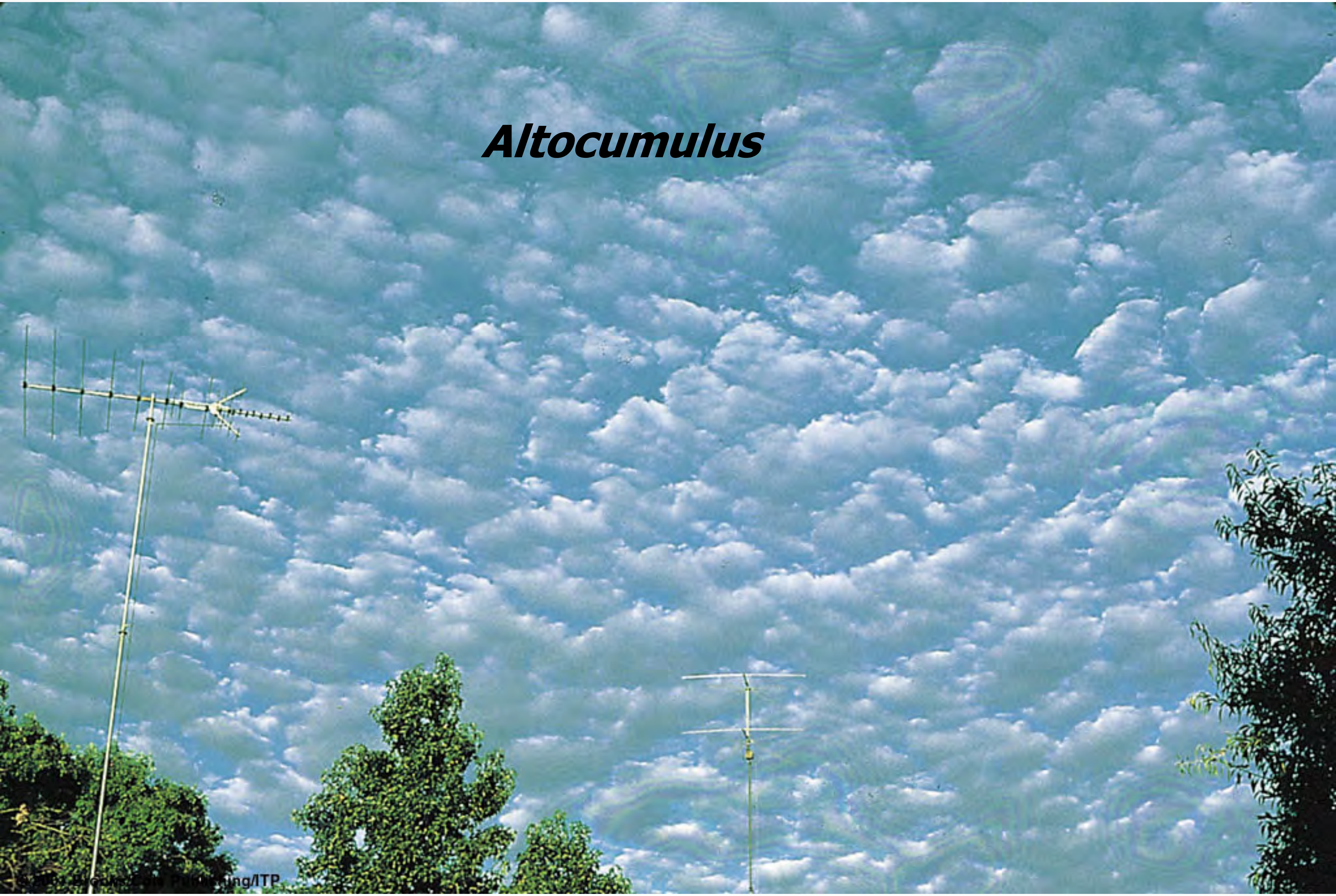


FIGURE 5.27 A generalized illustration of basic cloud types (genera) based on height above Earth's surface and the extent of vertical development.

Cumulus

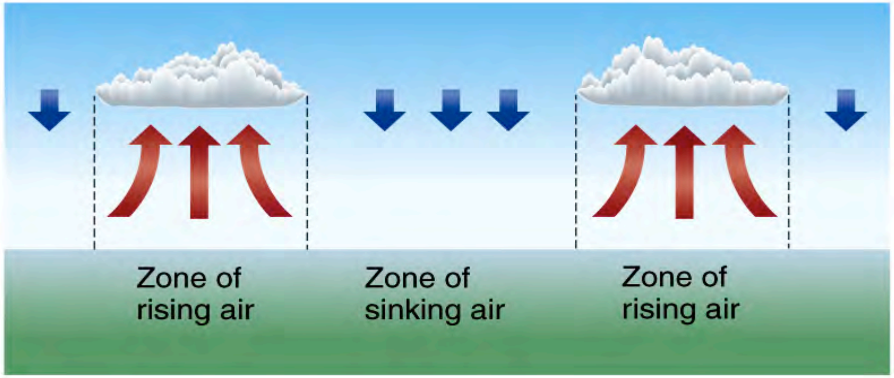
Stratocumulus


Altocumulus

Cirrocumulus

Altocumulus castellanus (ACC)

Cumulus humilis ‘Fair Weather’



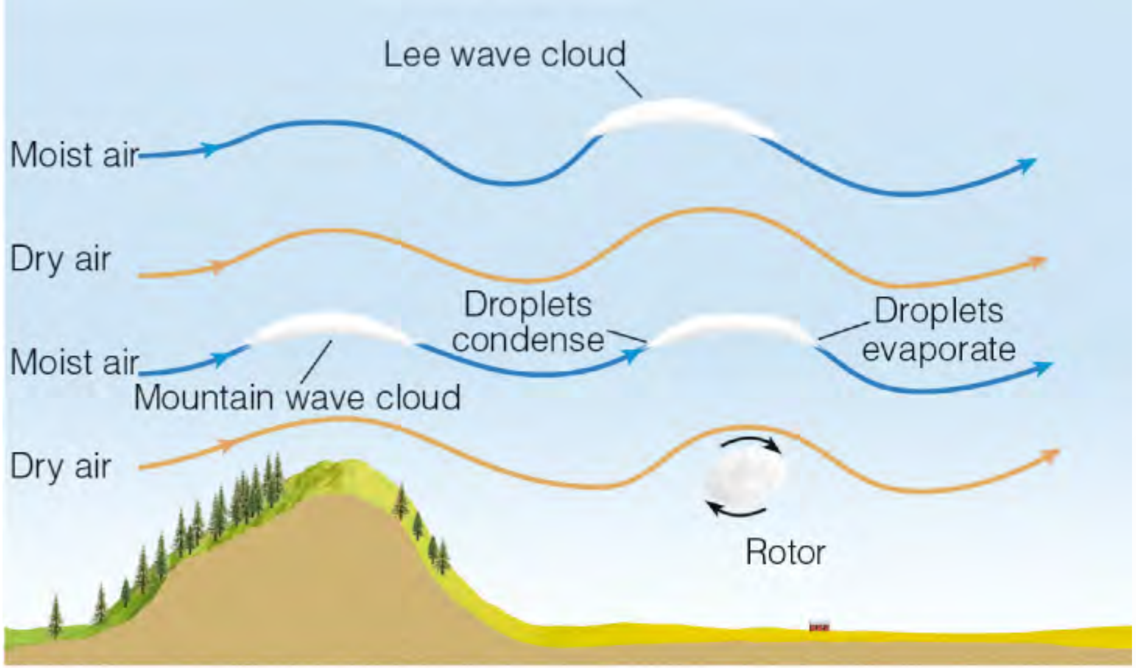
Cumulus congestus

Cumulonimbus

Shelf cloud

Lenticular Clouds

Ahrens: Fig. 5.28



Ahrens: Fig. 6.24

Banner clouds

Nacreous Clouds – Stratosphere

Noctilucent Clouds - Mesosphere

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. 11, p. 218

Midterm

- Marks out of 50/2.5 = 20% of term mark

Last year (out of 45)

- Average was 30, 67%
- Range from 41 to 20

See you on Thursday

I will do my best to answer email questions received by 6 pm Wednesday