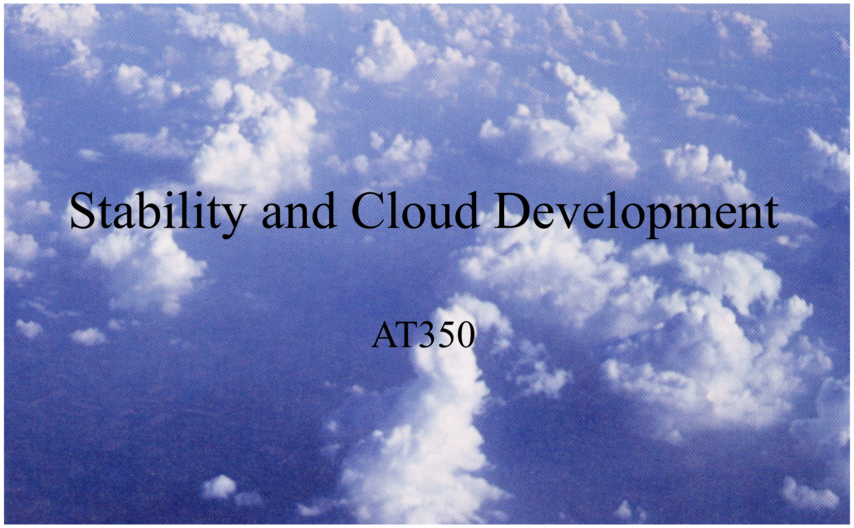
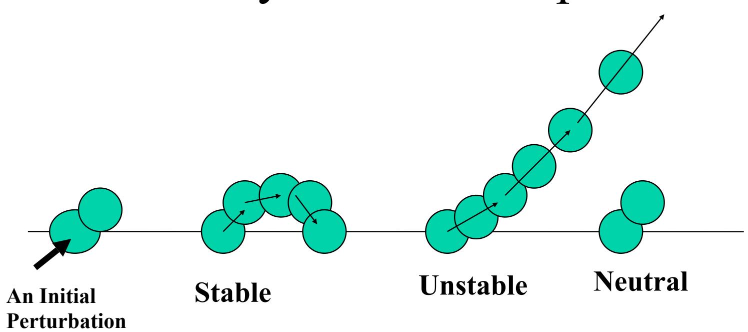
Stability and Cloud Development

AT350



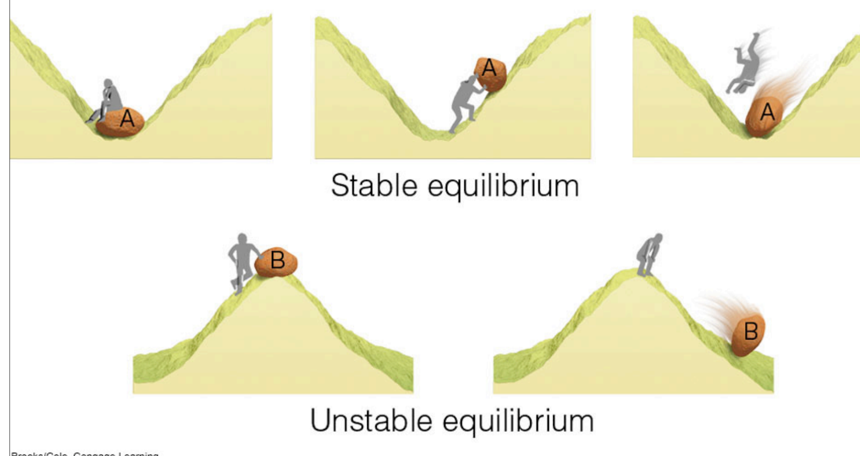
Why did this cloud form, whereas the sky was clear 4 hours ago?

Stability in the atmosphere



If an air parcel is displaced from its original height it can:

Return to its original height - Stable
Keep right on moving because it is buoyant - Unstable
Stay at the place to which it was displaced - Neutral



the concept of stability

Buoyancy

- An air parcel rises in the atmosphere when it's density is less than its surroundings
- Let ρ_{env} be the density of the environment. From the Equation of State/Ideal Gas Law

  $\rho_{env} = P/RT_{env}$
- Let ρ_{parcel} be the density of an air parcel. Then

  $\rho_{parcel} = P/RT_{parcel}$
- Since both the parcel and the environment at the same height are at the same pressure
  - When $T_{parcel} < T_{env}$ $\rho_{parcel} > \rho_{env}$
  - When $T_{parcel} > T_{env}$ $\rho_{parcel} < \rho_{env}$

What is the lapse rate?

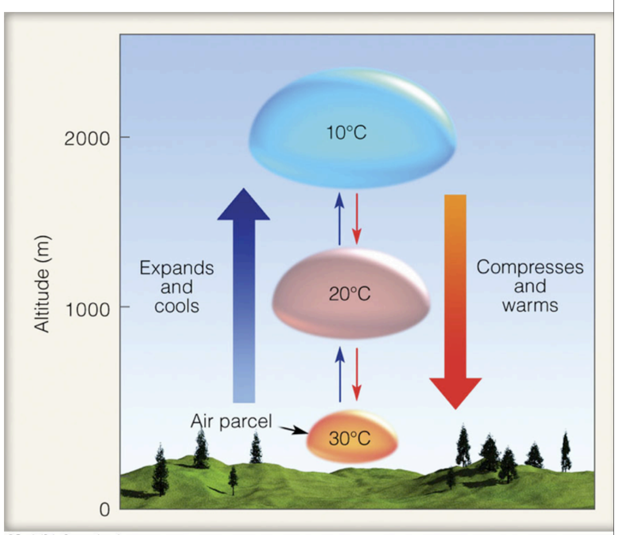
- The lapse rate is the change of temperature as a function of altitude
- There are two kinds of lapse rates:
  - Environmental Lapse Rate
    - What you would measure with a weather balloon
  - Parcel Lapse Rate
    - The change of temperature that an air parcel would experience when it is displaced vertically
    - This is assumed to be an *adiabatic process* (*i.e.*, no heat exchange occurs across parcel boundary)

Parcel lapse rate...

The atmospheric dry adiabatic lapse rate is ~

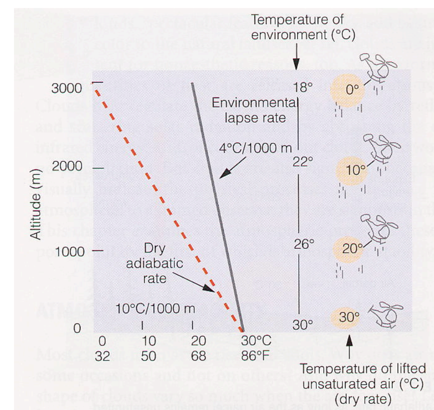
5.4 F/1000 ft
or
10 C/1000 m

The actual, environmental lapse rate may be greater or smaller than this



Stability and the dry adiabatic lapse rate

- Atmospheric stability depends on the environmental lapse rate
  - A rising unsaturated air parcel cools according to the dry adiabatic lapse rate
  - If this air parcel is
    - warmer than surrounding air it is less dense and buoyancy accelerates the parcel upward
    - Colder than surrounding air it is more dense and buoyancy forces oppose the rising motion



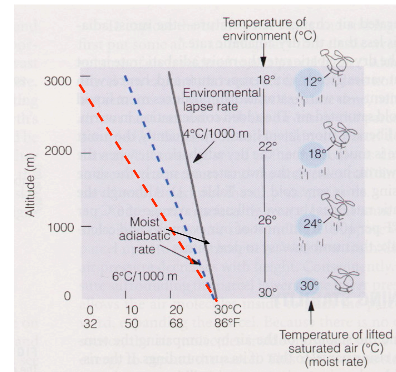
(a) Lifted, unsaturated air at each level is colder and heavier than the air around it. If given the chance, the parcel would return to its original position

A saturated rising air parcel cools less than an unsaturated parcel

- If a rising air parcel becomes saturated condensation occurs
- Condensation warms the air parcel due to the release of latent heat
- So, a rising parcel cools less if it is saturated
- Define a moist adiabatic lapse rate
  - ~ 6 C/1000 m
  - Not constant (varies from ~ 3-9 C)
  - depends on T and P

Stability and the moist adiabatic lapse

- Atmospheric stability depends on the environmental lapse rate
  - A rising saturated air parcel cools according to the moist adiabatic lapse rate
  - When the environmental lapse rate is smaller than the moist adiabatic lapse rate, the atmosphere is termed *absolutely stable*
    - Recall that the dry adiabatic lapse rate is larger than the moist
  - What types of clouds do you expect to form if saturated air is forced to rise in an absolutely stable atmosphere?



(b) Lifted, saturated air at each position is colder and heavier than the air surrounding it. If released, the parcel would return to its original position.

What conditions contribute to a stable atmosphere?

- Radiative cooling of surface at night
- Advection of cold air near the surface
- Air moving over a cold surface (e.g., snow)
- Adiabatic compression due to subsidence (sinking)

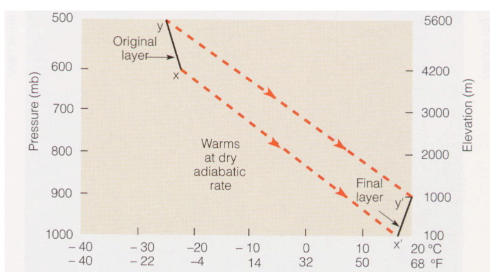
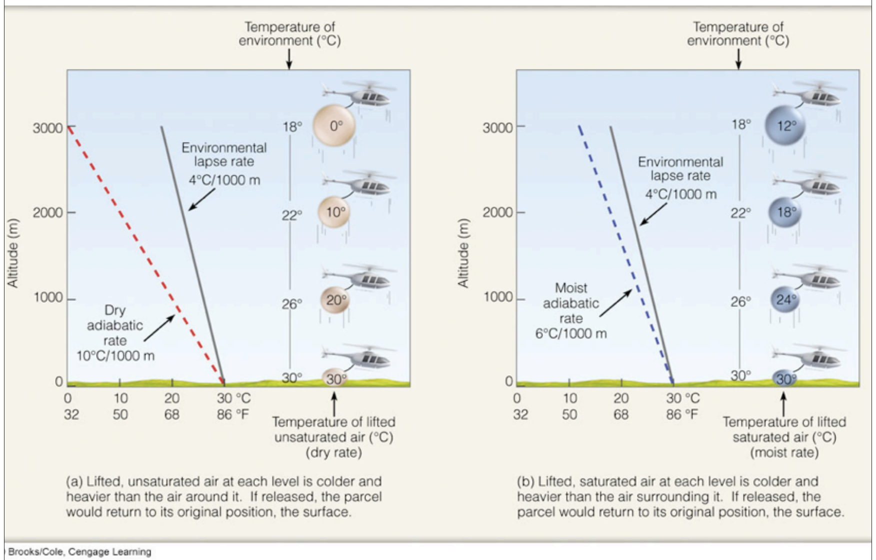


FIGURE 7.5
The layer x–y is initially 1400 m thick. If the entire layer slowly subsides, it shrinks in the more-dense air near the surface. As a result of the shrinking, the top of the layer warms more than the bottom, and the entire layer (x'–y') becomes more stable.

Absolute instability

- The atmosphere is absolutely unstable if the environmental lapse rate exceeds the moist and dry adiabatic lapse rates
- This situation is not long-lived
  - Usually results from surface heating and is confined to a shallow layer near the surface
  - Vertical mixing can eliminate it

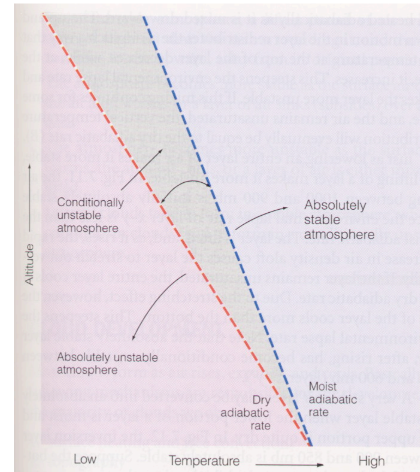


(a) Lifted, unsaturated air at each level is colder and heavier than the air around it. If released, the parcel would return to its original position, the surface.

(b) Lifted, saturated air at each level is colder and heavier than the air surrounding it. If released, the parcel would return to its original position, the surface.

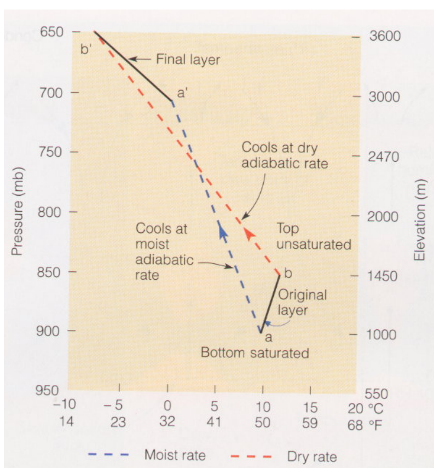
Conditionally unstable air

- What if the environmental lapse rate falls between the moist and dry adiabatic lapse rates?
  - The atmosphere is unstable for saturated air parcels but stable for unsaturated air parcels
  - This situation is termed *conditionally unstable*
- This is the typical situation in the atmosphere



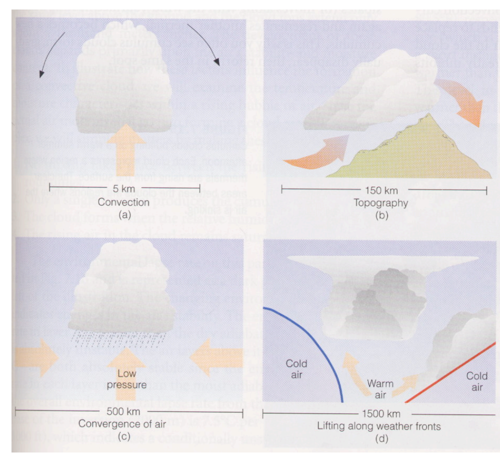
What conditions enhance atmospheric instability?

- Cooling of air aloft
  - Cold advection aloft
  - Radiative cooling of air/clouds aloft
- Warming of surface air
  - Solar heating of ground
  - Warm advection near surface
  - Air moving over a warm surface (e.g., a warm body of water)
    - Contributes to lake effect snow
- Lifting of an air layer and associated vertical "stretching"
  - Especially if bottom of layer is moist and top is dry



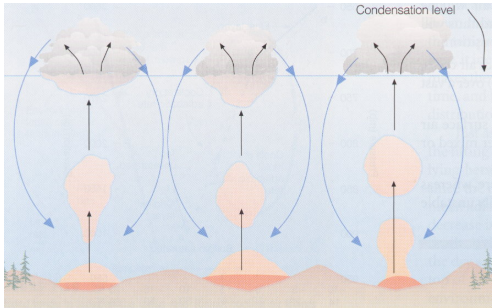
Cloud development

- Clouds form as air rises, expands and cools
- Most clouds form by
  - Surface heating and free convection
  - Lifting of air over topography
  - Widespread air lifting due to surface convergence
  - Lifting along weather fronts



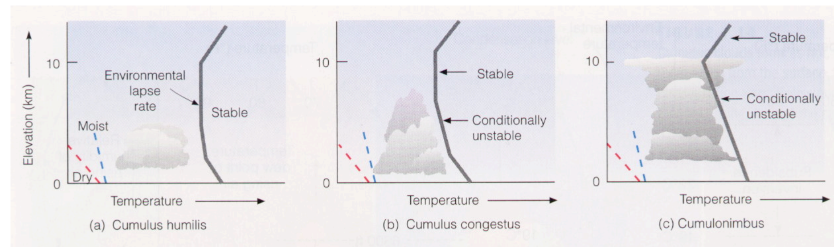
Fair weather cumulus cloud development

- Air rises due to surface heating
- RH rises as rising parcel cools
- Cloud forms at RH ~ 100%
- Rising is strongly suppressed at base of subsidence inversion produced from sinking motion associated with high pressure system
- Sinking air is found between cloud elements
  - Why?



What conditions support taller cumulus development ?

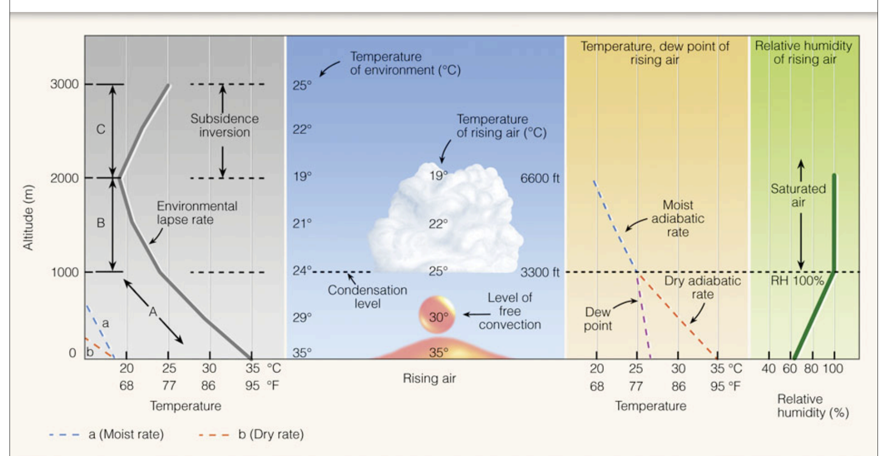
- A less stable atmospheric profile permits greater vertical motion



Determining Convective Cloud Bases

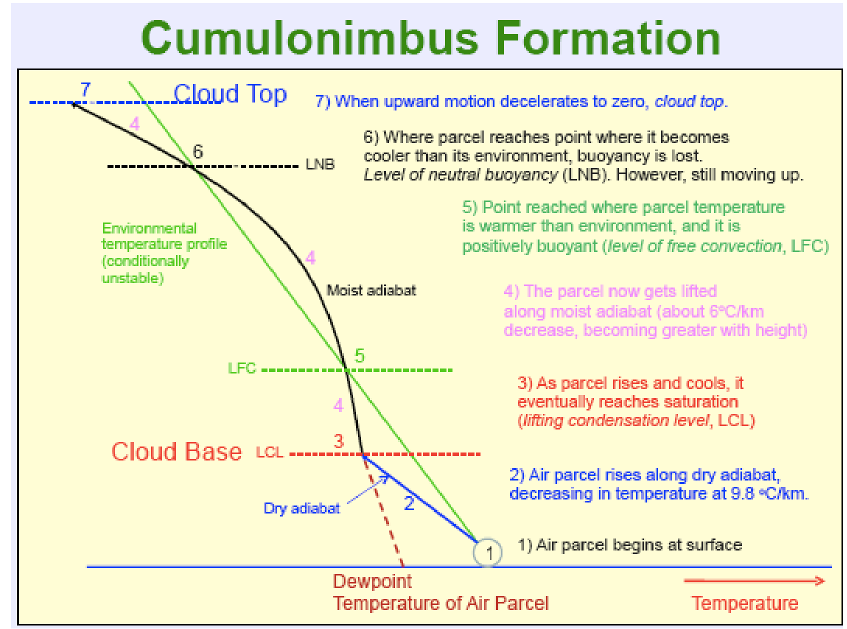
- Dry air parcels cool at the dry adiabatic rate (about 10 ^{o}C/km
- Dew point decreases at a rate of ~ 2 ^{o}C/km
- This means that the dew point approaches the air parcel temperature at a rate of about 8^{o}C/km
- If the dew point depression were 8^{o}C at the surface, a cloud base would appear at a height of 1000 meters; 4 C at 500 meters etc.
  - Cloud base occurs when dew point = temp (100% RH)
- Each one degree difference between the surface temperature and the dew point will produce an increase in the elevation of cloud base of 125 meters

Fair weather cumulus cloud development schematic



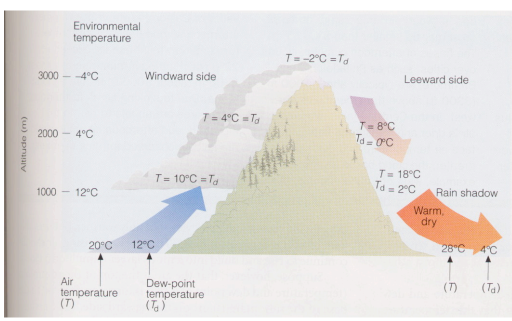
Determining convective cloud top

- **Cloud top will be defined by the upper boundary of air parcel rising motion**
- **The area between the dry/moist adiabatic lapse rate, showing an air parcel's temperature during ascent, and the environmental lapse rate, can be divided into two parts**
  - A positive acceleration part where the parcel is warmer than the environment
  - A negative acceleration part where the parcel is colder than the environment
- **The approximate cloud top height will be that altitude where the negative acceleration area becomes nominally equal to the positive acceleration area**

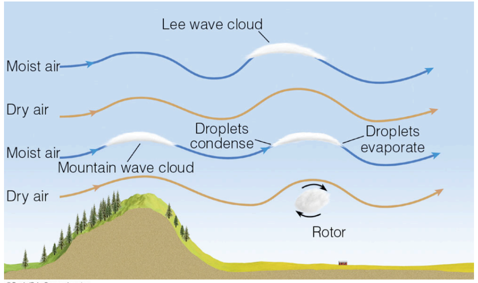


Orographic clouds

- Forced lifting along a topographic barrier causes air parcel expansion and cooling
- Clouds and precipitation often develop on upwind side of obstacle
- Air dries further during descent on downwind side



some examples of clouds in stable and unstable layers


Lee wave cloud
Moist air
Dry air
Droplets condense
Droplets evaporate
Moist air
Mountain wave cloud
Dry air
Rotor