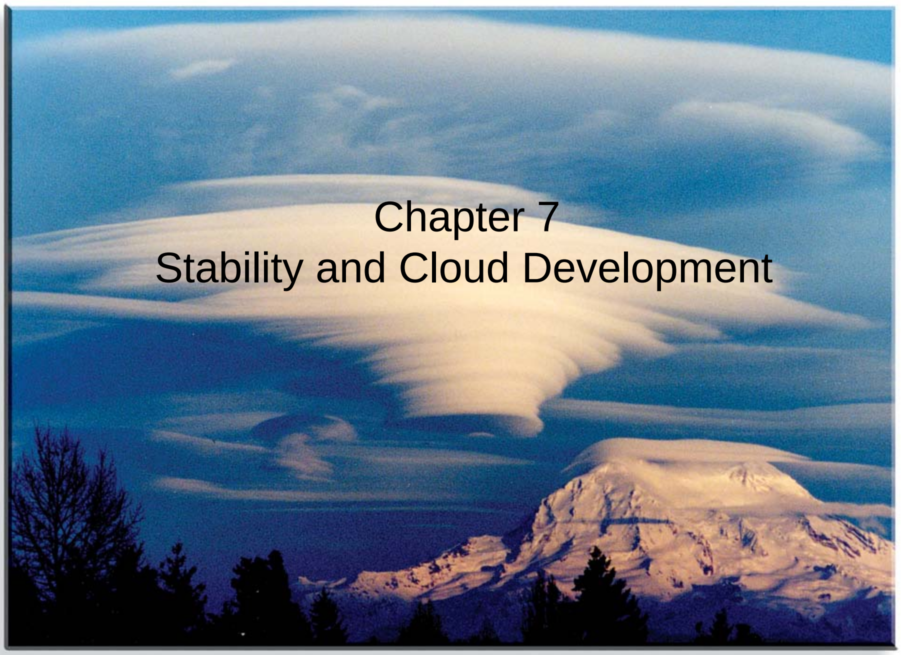

Chapter 7
Stability and Cloud Development

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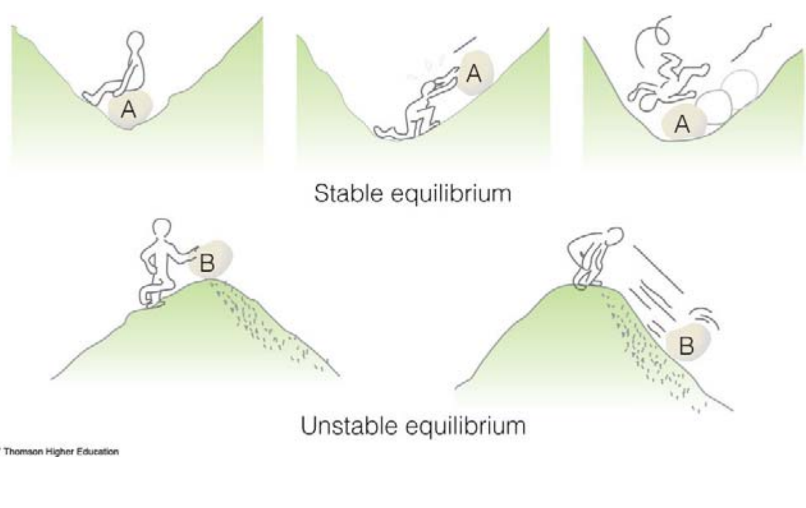
Atmospheric Stability



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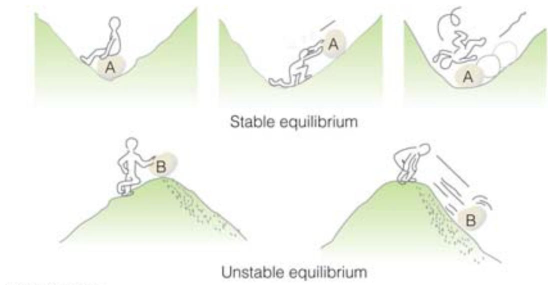
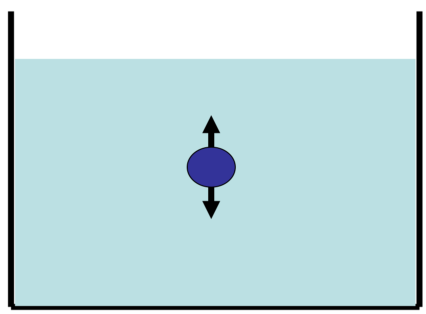
Cloud Development - stable environment

- ***Stable air (parcel)*** - vertical motion is inhibited
  - if clouds form, they will be shallow, layered clouds like stratus
- **Cloud Development - unstable environment**
  - *Unstable air (parcel)* - vertical motion occurs
  - commonly produces cumulus, cumulonimbus clouds



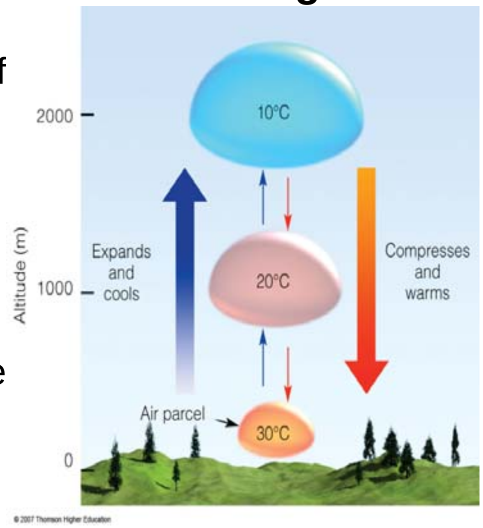
How to determine atmospheric Stability?



- A ball in water:
  - When does it rise?
  - When does it sink?
- An air parcel:
  - Density
  - Lighter than environment, it will rise.
  - Heavier than environment, it will sink.
- What determine air density at a given pressure:
  - Temperature

Determining Air Parcel Temperature: Rising air parcels and adiabatic cooling

- consider a rising parcel of air **-->>**
- As the parcel rises, it will *adiabatically expand and cool*
- *adiabatic* - a process where the parcel temperature changes due to an expansion or compression, **no heat is added or taken away from the parcel**



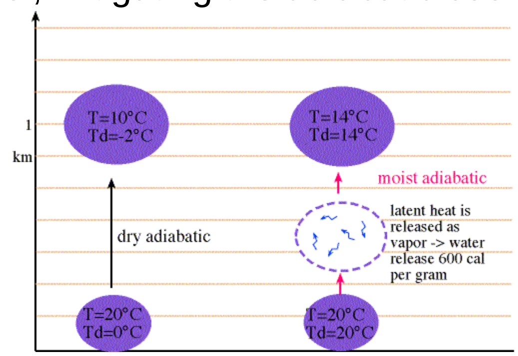
Consider a sinking parcel of air **-->>**

Adiabatic lapse rate

- As a parcel of air rises, it cools, but at what rate?
- **Lapse rate**
  - rate of temperature change with height
  - units of lapse rate are °C km^{-1}
- **Dry-adiabatic lapse rate**
  - unsaturated parcels cool at a rate of 10°C km^{-1} - this is called the *dry-adiabatic lapse rate*
- **Moist Adiabatic Lapse Rate**
  - For a saturated parcel of air, i.e., when its T=Td, then it cools at the *moist adiabatic lapse rate* = 6°C km^{-1}
- Q: Why does the parcel cool at a slower rate (6 °C km^{-1}) when it is saturated than at 10°C km^{-1} when it is unsaturated?

Dry versus Moist-Adiabatic Process

- the moist adiabatic lapse rate is less than the dry adiabatic lapse rate because as vapor condenses into water (or water freezes into ice) for a saturated parcel, latent heat is released into the parcel, mitigating the adiabatic cooling



Moist adiabatic lapse rate: vary with temperature and pressure

•TABLE 6.1

The Moist Adiabatic Rate for Different Temperatures and Pressures in °C/1000 m and °F/1000 ft

PRESSURE (MB)	TEMPERATURE (°C) −40	−20	0	20	40	TEMPERATURE (°F) −40	−5	30	65	100
1000	9.5	8.6	6.4	4.3	3.0	5.2	4.7	3.5	2.4	1.6
800	9.4	8.3	6.0	3.9		5.2	4.6	3.3	2.2	
600	9.3	7.9	5.4			5.1	4.4	3.0		
400	9.1	7.3				5.0	4.0			
200	8.6					4.7				

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Assessing Atmospheric Stability

- The bottom line -
  - To determine whether or not a parcel will rise or sink in the atmosphere, one must compare the parcels temperature (T_p) with that of the environment (T_e) at some altitude:
  - if $T_p > T_e$ what will the parcel do?
  - if $T_p = T_e$ what will the parcel do?
  - if $T_p < T_e$ what will the parcel do?
- So, to assess stability, what two pieces of information do we need?

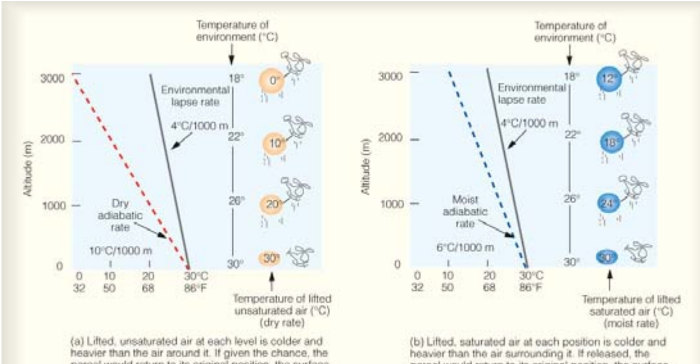
Absolute Stability

- Generally, notice that T_e is always larger than T_{sp} and T_{up} at any level
  - Hence, an unsaturated or saturated parcel will **always be cooler** than the environment and will sink back down to the ground
- The condition for absolute stability is:
  - $\boldsymbol{\Gamma_d > \Gamma_m > \Gamma_e}$
  - Γ_d is the *dry adiabatic lapse rate* (10°C km^{-1})
  - Γ_m is the *moist adiabatic lapse rate* (6°C km^{-1})
  - Γ_e is the *environmental lapse rate*

T_{up}: the temperature of an unsaturated parcel

T_{sp}: temperature of a saturated parcel

T_e: environmental temperature



(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, the surface.

(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, the surface.

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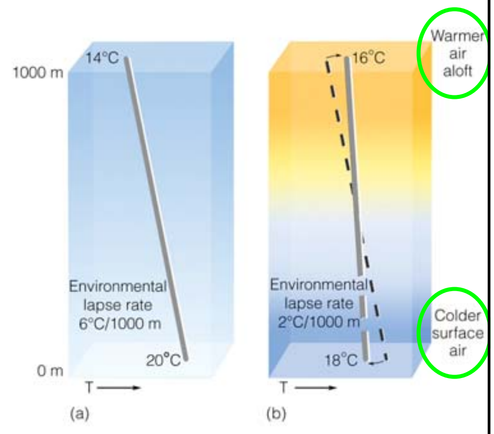
Stability of Inversion Layers

- Q: How would you characterize the stability of an inversion layer?
  - They are *absolutely stable*
- Note that the absolute stability criteria: $\Gamma_e < \Gamma_m < \Gamma_d$

- Q: How do you form stable layers in the atmosphere?
  - Radiational Cooling - radiation inversion
  - cold air moving in at low levels
  - warm air moving over cold ground



Cold surface air, on this morning, produces a stable atmosphere that inhibits vertical air motions and allows the fog and haze to linger close to the ground.

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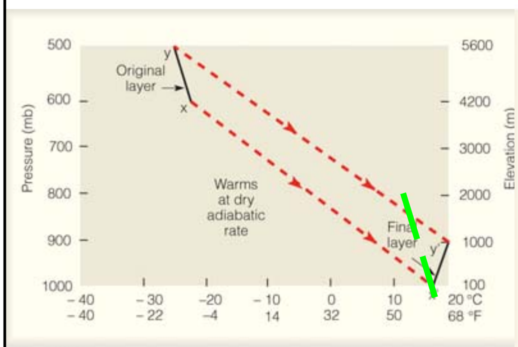
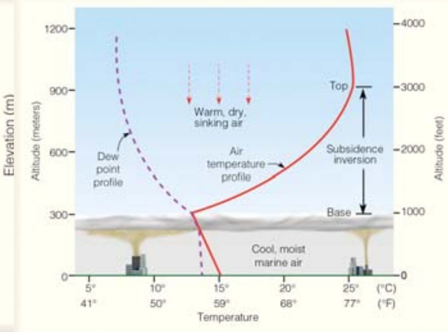
Formation of Subsidence Inversions

- How does the stability change for a descending layer of air?

The top of the layer warms more than the bottom



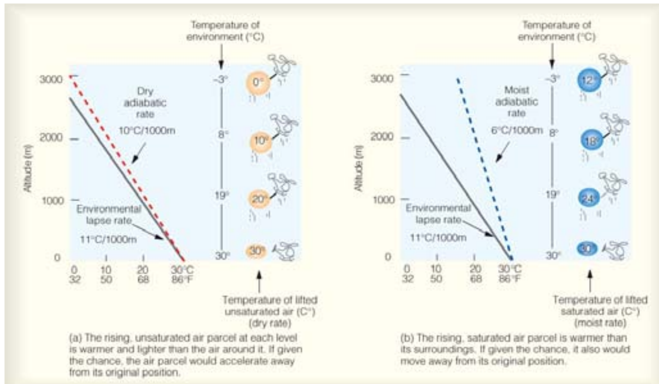


Natural Stability

- The environmental lapse rate is equal to the dry adiabatic rate.
- Or when parcel is saturate: …

Absolute Instability

- The condition for absolute instability is:
  - $\Gamma_e > \Gamma_d > \Gamma_m$
- Hence, an unsaturated or saturated parcel will always be ***warmer*** than the environment and will continue to ascend



(a) The rising, unsaturated air parcel at each level is warmer and lighter than the air around it. If given the chance, the air parcel would accelerate away from its original position.

(b) The rising, saturated air parcel is warmer than its surroundings. If given the chance, it also would move away from its original position.

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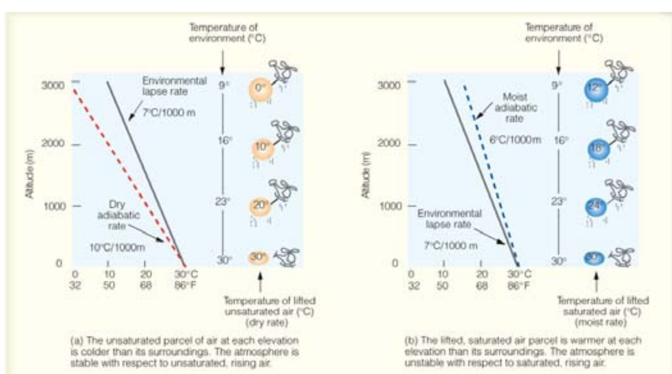
Conditional Instability

- The condition for conditional instability is:
  - $\Gamma_d > \Gamma_e > \Gamma_m$
- The **unsaturated parcel** will be ***cooler*** than then environment and will sink back to the ground
- The **saturated parcel** will be **warme**r than the environment and will continue to ascend



(a) The unsaturated parcel of air at each elevation is colder than its surroundings. The atmosphere is stable with respect to unsaturated, rising air.

(b) The lifted, saturated air parcel is warmer at each elevation than its surroundings. The atmosphere is unstable with respect to saturated, rising air.

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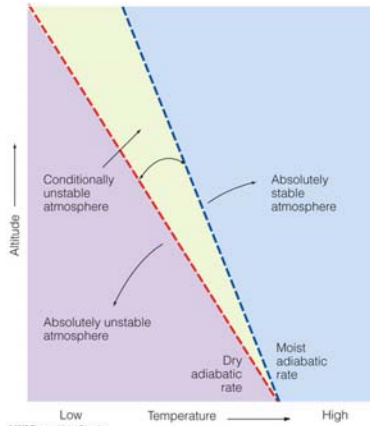
Stability of the environment

- To determine the environmental stability, one must calculate the lapse rate for a sounding
- lapse rate = -DT/DZ = (T2-T1)/(Z2-Z1)
- Since the environment is often composed of layers with different stabilities, it is useful to first identify these layers and then calculate their respective lapse rates

  - recall the stability criteria:
    - $\Gamma_e < \Gamma_m$ **- Absolutely stable**
    - $\Gamma_m < \Gamma_e < \Gamma_d$ **- Conditional Instability**
    - $\Gamma_m < \Gamma_d < \Gamma_e$ **- Absolutely unstable**



Processes that destabilize the atmosphere

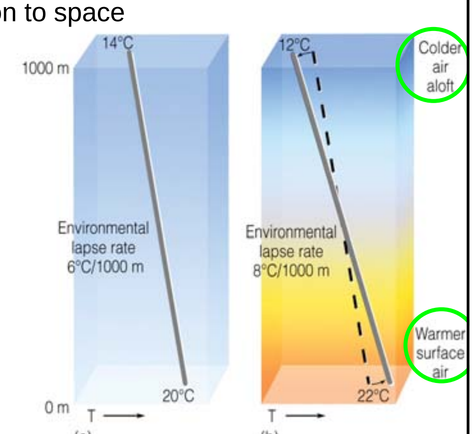
1. By cooling of the air aloft and Warming of the surface air

Cooling of the air aloft

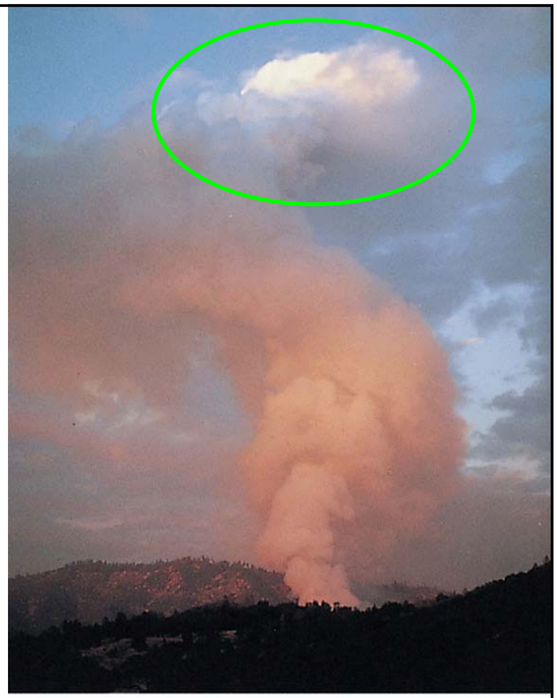
- Cold air moving is aloft
  - this often occurs when an extra tropical cyclone passes overhead
- Clouds or air emitting IR radiation to space

Warming of the surface air

- Surface Heating - suggests that the atmosphere will be most unstable. When?
- Warm air moving in at low levels
  - this often occurs ahead of a cold front
- Cold air moving over a warm surface:
  - Such as lake effect snow



The warmth from the forest fire heats the air, causing instability near the surface. Warm, less-dense air (and smoke) bubbles upward, expanding and cooling as it rises. Eventually the rising air cools to its dew point, condensation begins, and a cumulus cloud forms.



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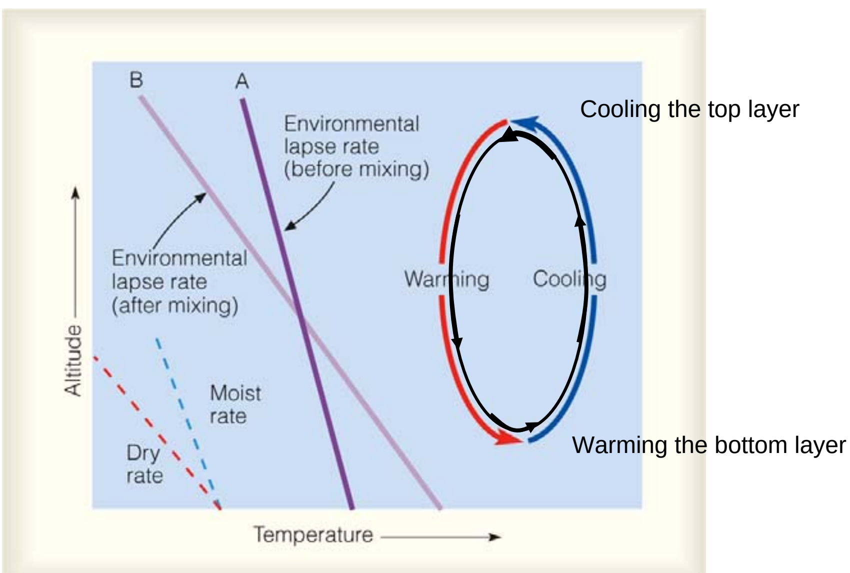
2. Destabilize the atmosphere by mixing



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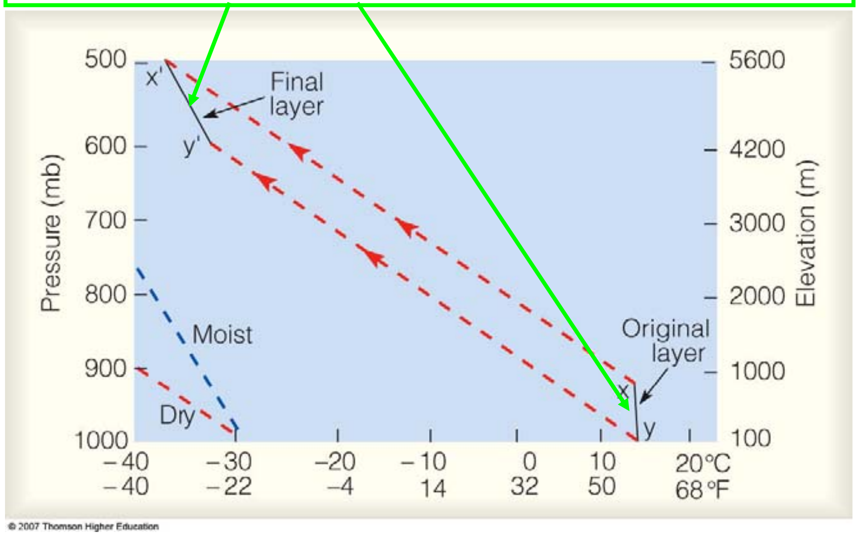
3. Destabilize the atmosphere by lifting

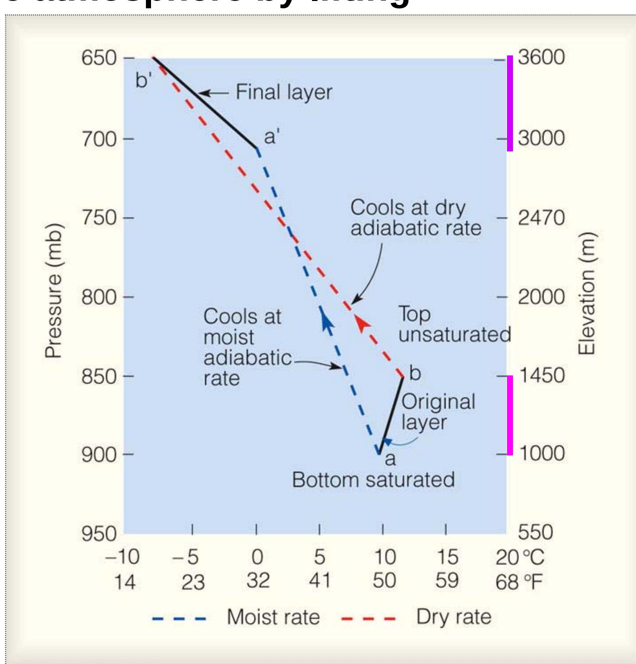
The vertical stretch of the **unsaturated layer** cools the top of the layer more than the bottom—conditionally unstable.



3. Destabilize the atmosphere by lifting

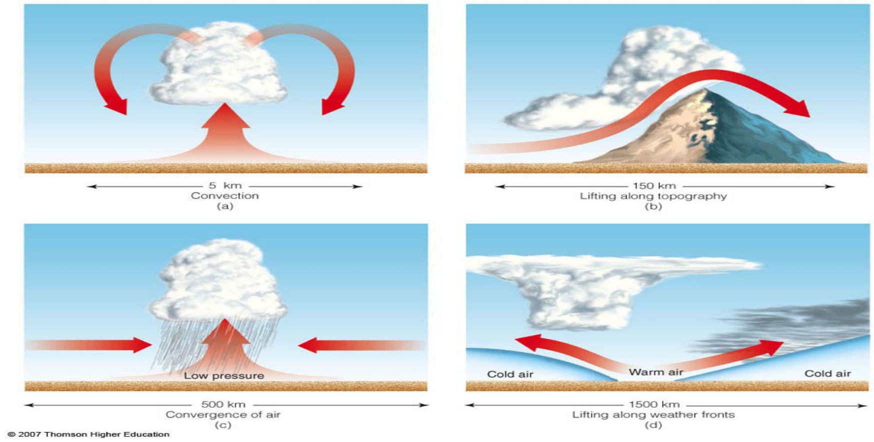
The vertical stretch of a **bottom saturated and top unsaturated** layer cools the top of the layer more than the bottom—absolutely unstable.

Convective instability



Atmospheric Instability and Cloud Development

1. **How are vertical parcel motions that create clouds generated naturally in the atmosphere?**
   - Surface heating and free convection
   - Topography
   - Widespread ascent due to convergence of surface air
   - Uplift along weather fronts



Atmospheric Instability and Cloud Development - lifting mechanisms

2. What kind (if any) clouds will you visually observe in different stable environments?

In ***an absolutely stable environment***, no clouds will likely form.

In a ***shallow conditionally unstable or absolutely unstable environment***, one may expect clouds to develop, but their vertical growth will be limited, and may observe:

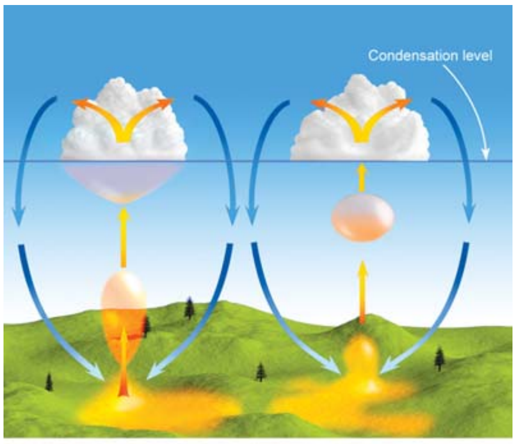
cumulus humilis (shallow cumulus)
stratocumulus

In ***a deep conditionally unstable or absolutely unstable environment***, one may expect clouds to develop with significant vertical development, and may observe:

cumulus congestus
cumulonimbus

Cloud Development - Convection

- Convection usually occurs when the surface is heated and a surface parcel becomes warmer than the environment **-->**
- the vertical extent of the cloud is largely determined by the stability of the environment...

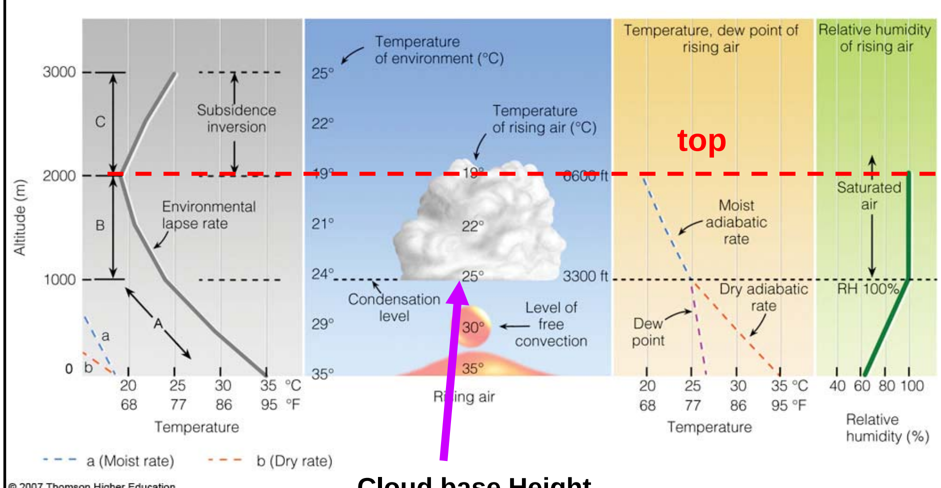


Cumulus clouds form as hot, invisible air bubbles detach themselves from the surface, then rise and cool to the condensation level. Below and within the cumulus clouds, the air is rising. Around the cloud, the air is sinking.

The development of a cumulus cloud

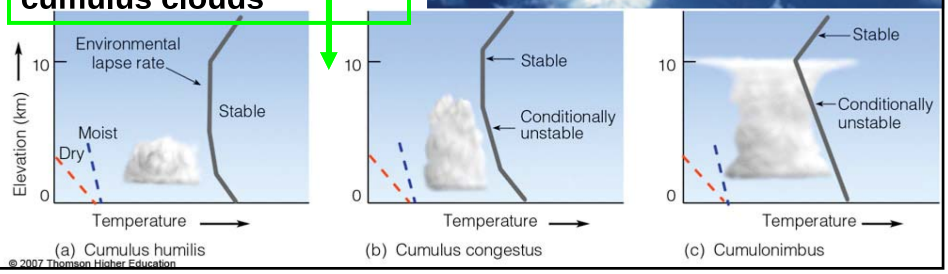
Layer A: Absolutely unstable   Layer B or C: Absolutely stable

Layer A and B on average: conditional unstable



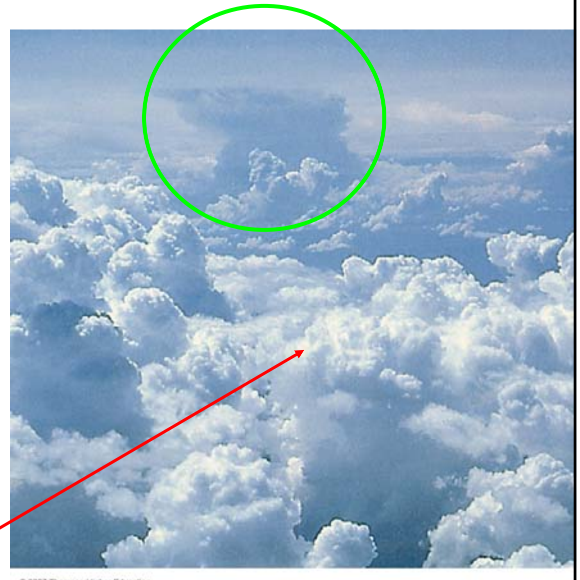
Cumulus clouds building on a warm summer afternoon. Each cloud represents a region where thermals are rising from the surface. The clear areas between the clouds are regions where the air is sinking.

The air's stability greatly influences the growth of cumulus clouds



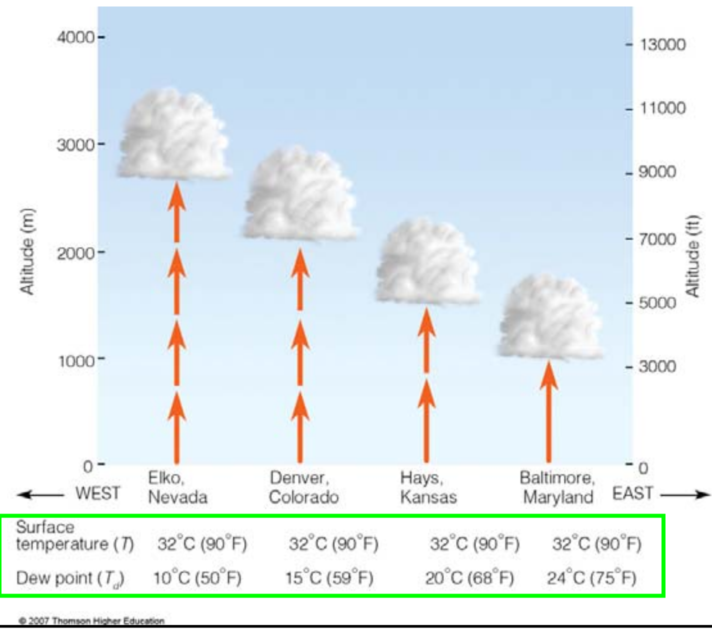
cumulonimbus

Cumulus clouds developing into thunderstorms in a conditionally unstable atmosphere over the Great Plains. Notice that, in the distance, the cumulonimbus with the anvil top has reached the stable part of the atmosphere.



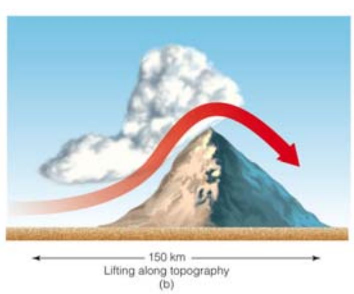
Cumulus Congestus

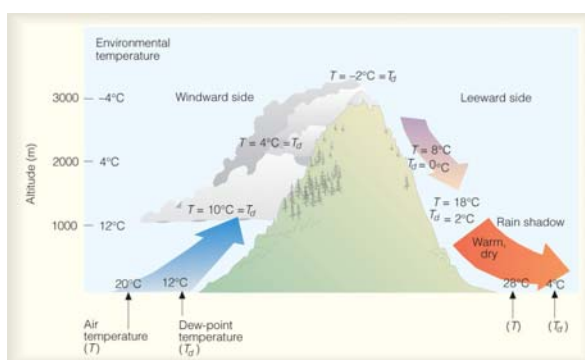
What determines cumulus cloud bases height?



Cloud Development - Topographic Lifting

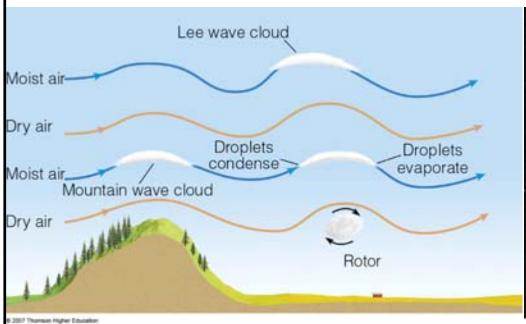
- Simply, air is forced up and over a topographical barrier - such as a hill or mountain
- The windward side will be cloudy and wet as air ascends
- The leeward side will be warmer and drier as the air descends - often called a *rain shadow*



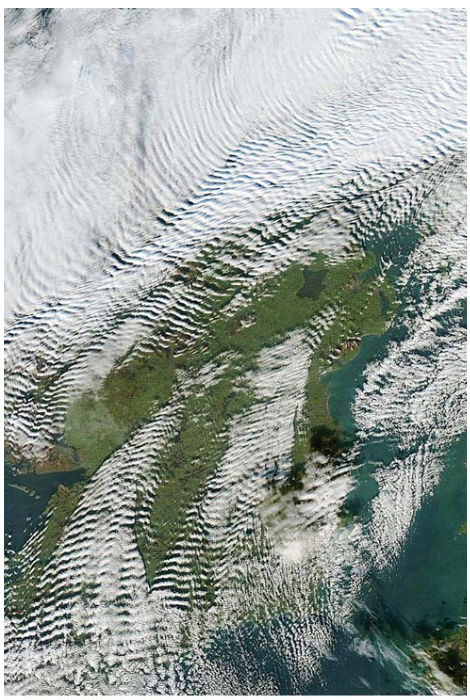


Topographic Lifting - Wave Clouds

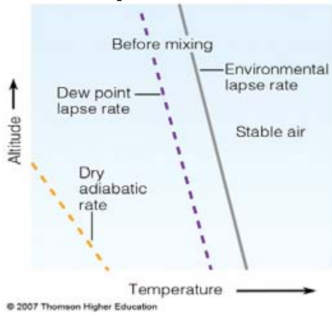
- If air being forced over a topographical barrier is stable, then wave clouds often form
- Lenticular clouds are an example
- Wave clouds are often aligned in "waves" and are often visible in satellite imagery..

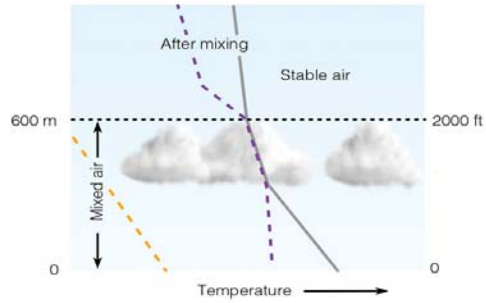


Satellite view of wave clouds forming many kilometers downwind of the mountains in Scotland and Ireland.



The mixing of a moist layer of air near the surface can produce a deck of stratocumulus clouds



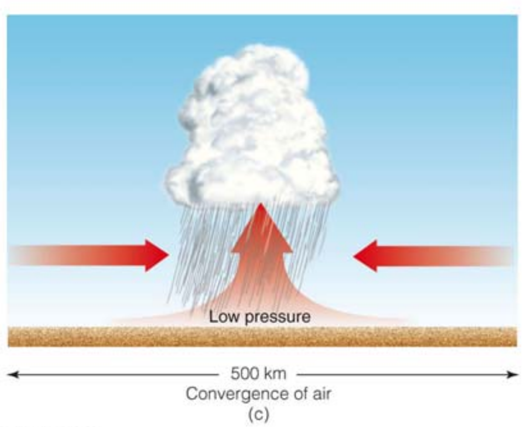


Cold air move over warm surface

Stratocumulus clouds forming in rows over the Atlantic ocean as cold, dry arctic air sweeps over Canada

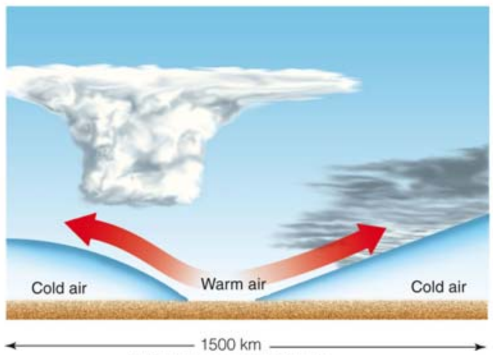
Cloud Development - Convergence

- if air converges to a given location near the surface:
  - it can't "pile up" at that point
  - it can't go downward, the ground is there
  - it must go up!
- common at the center of an extra-tropical cyclone



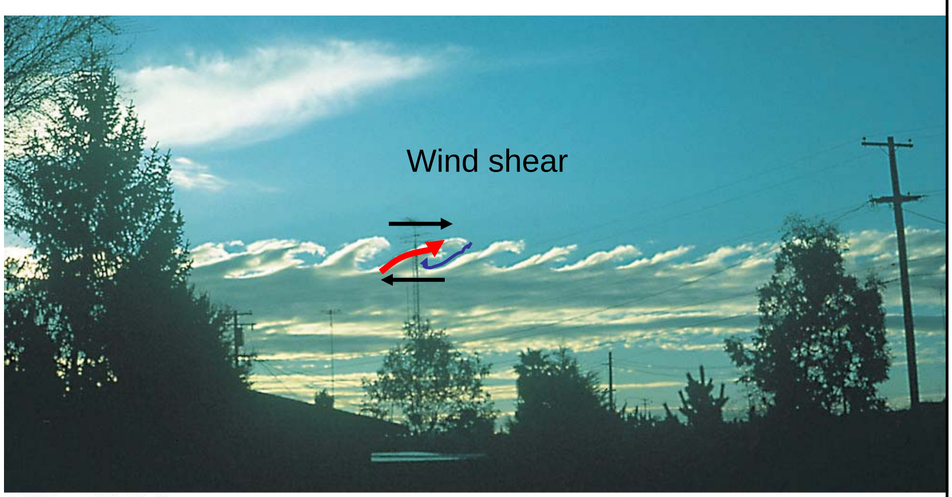
Cloud Development - Frontal Lifting

- If air is lifted into a stable layer:
  - stratus or nimbostratus clouds are often the result (common along warm fronts)
- if air is lifted into a conditionally unstable layer:
  - cumulus or cumulonimbus are often the result (common along cold fronts)



Lifting along weather fronts
(d)

Billow clouds forming in a region of rapidly changing wind speed, called wind shear.



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