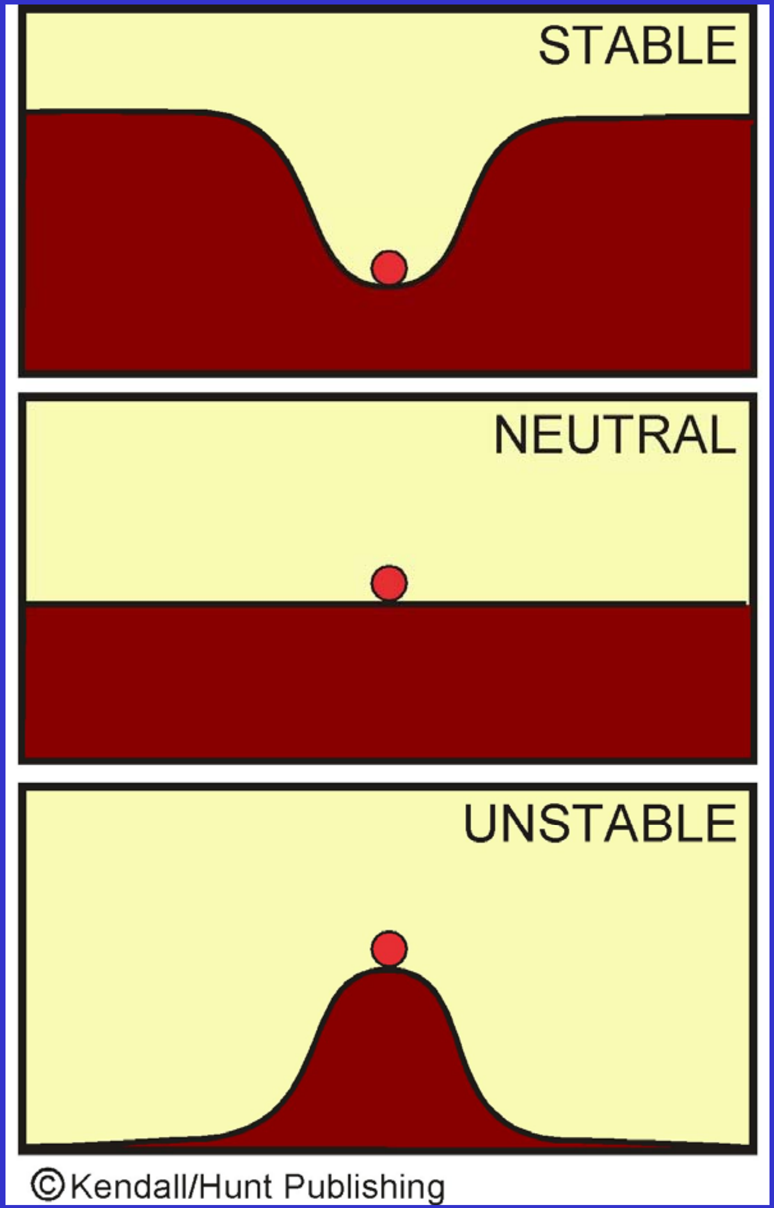
Chapter 6: Stability

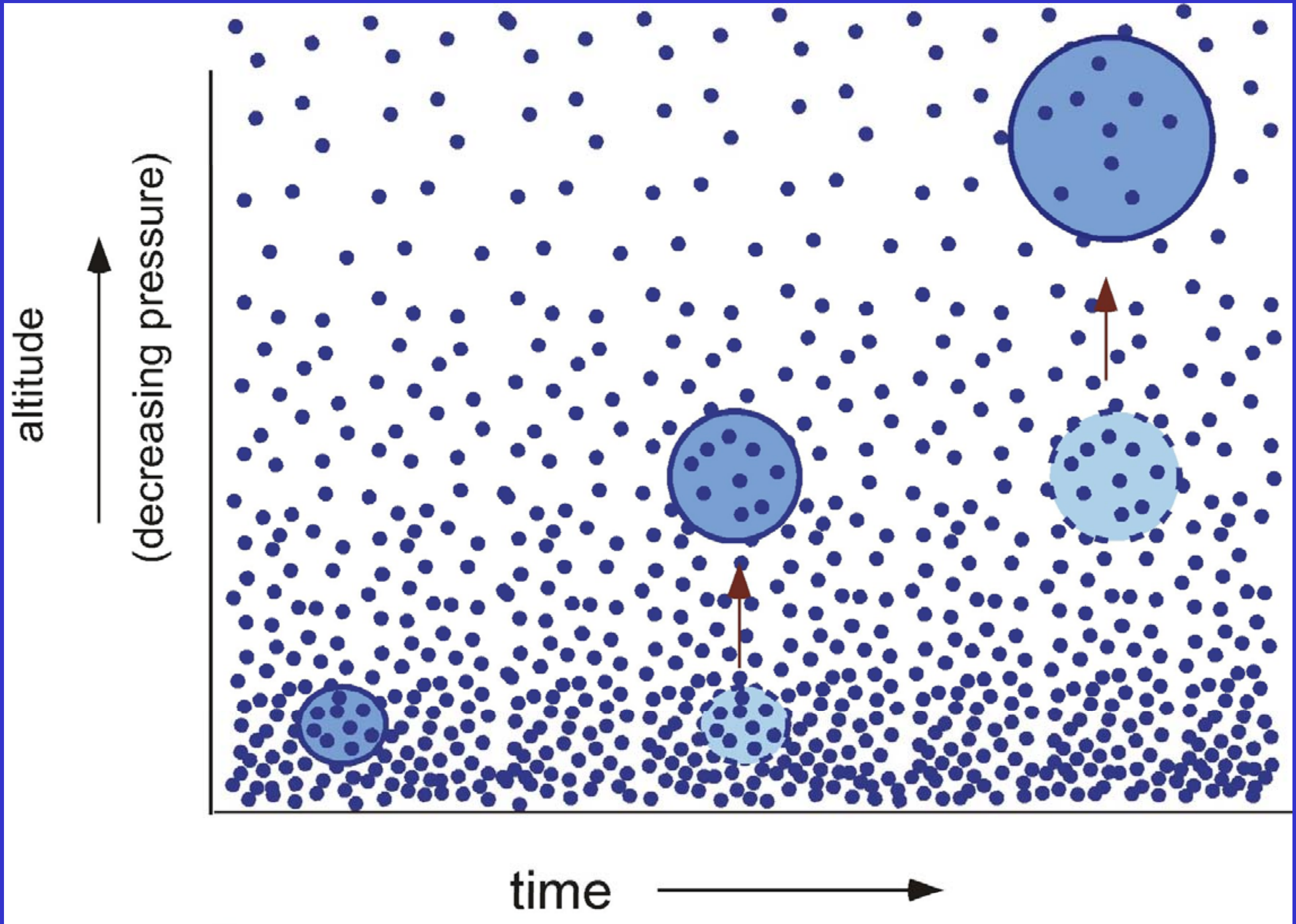
Courtesy of Glen Romine

- Concept of Stability
- Lapse Rates
- Determine Stability and Stability Indices

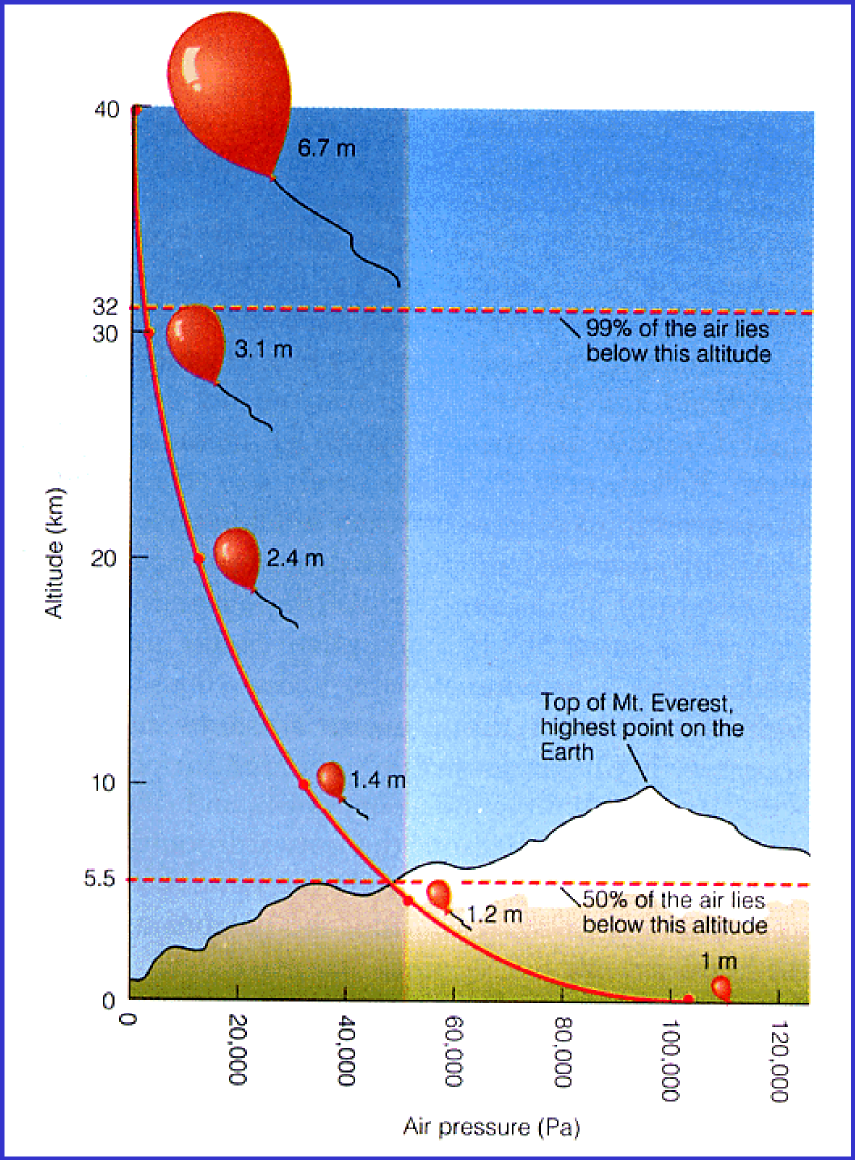
Concept of Stability



Air Parcel Expands as It Rises



Air Parcel Expands As It Rises…



(from *The Blue Planet*)

- Air pressure decreases with elevation.
- If a helium balloon 1 m in diameter is released at sea level, it expands as it floats upward because of the pressure decrease. The balloon would be 6.7 m in diameter as a height of 40 km.

What Happens to the Temperature?

- Air molecules in the parcel (or the balloon) have to use their kinetic energy to expand the parcel/balloon.

- Therefore, the molecules lost energy and slow down their motions

➔ The temperature of the air parcel (or balloon) decreases with elevation. The lost energy is used to increase the potential energy of air molecular.

- Similarly when the air parcel descends, the potential energy of air molecular is converted back to kinetic energy.

  ➔ Air temperature rises.

Adiabatic Process

- If a material changes its state (pressure, volume, or temperature) without any heat being added to it or withdrawn from it, the change is said to be adiabatic.

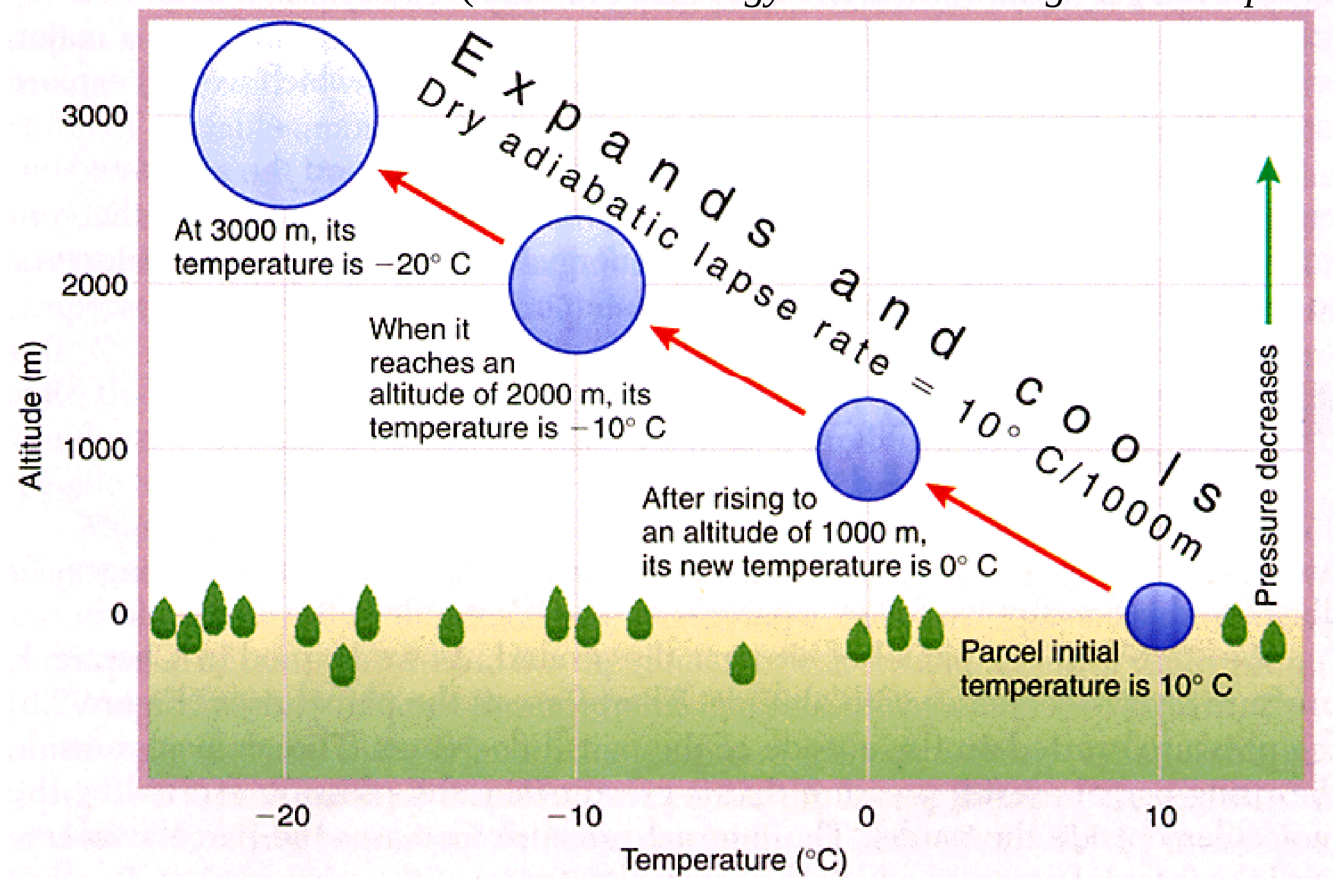
- The adiabatic process often occurs when air rises or descends and is an important process in the atmosphere.

Diabatic Process

- Involve the direct addition or removal of heat energy.
- Example: Air passing over a cool surface loses energy through conduction.

Dry Adiabatic Lapse Rate

(from *Meteorology: Understanding the Atmosphere*)



- Air parcels that do not contain cloud (are not saturated) cool at the dry adiabatic lapse rate as they rise through the atmosphere.
- Dry adiabatic lapse rate = 10°C/1km

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Lapse Rates

- A lapse rate is the rate at which temperature decreases (lapses) with increasing altitude.

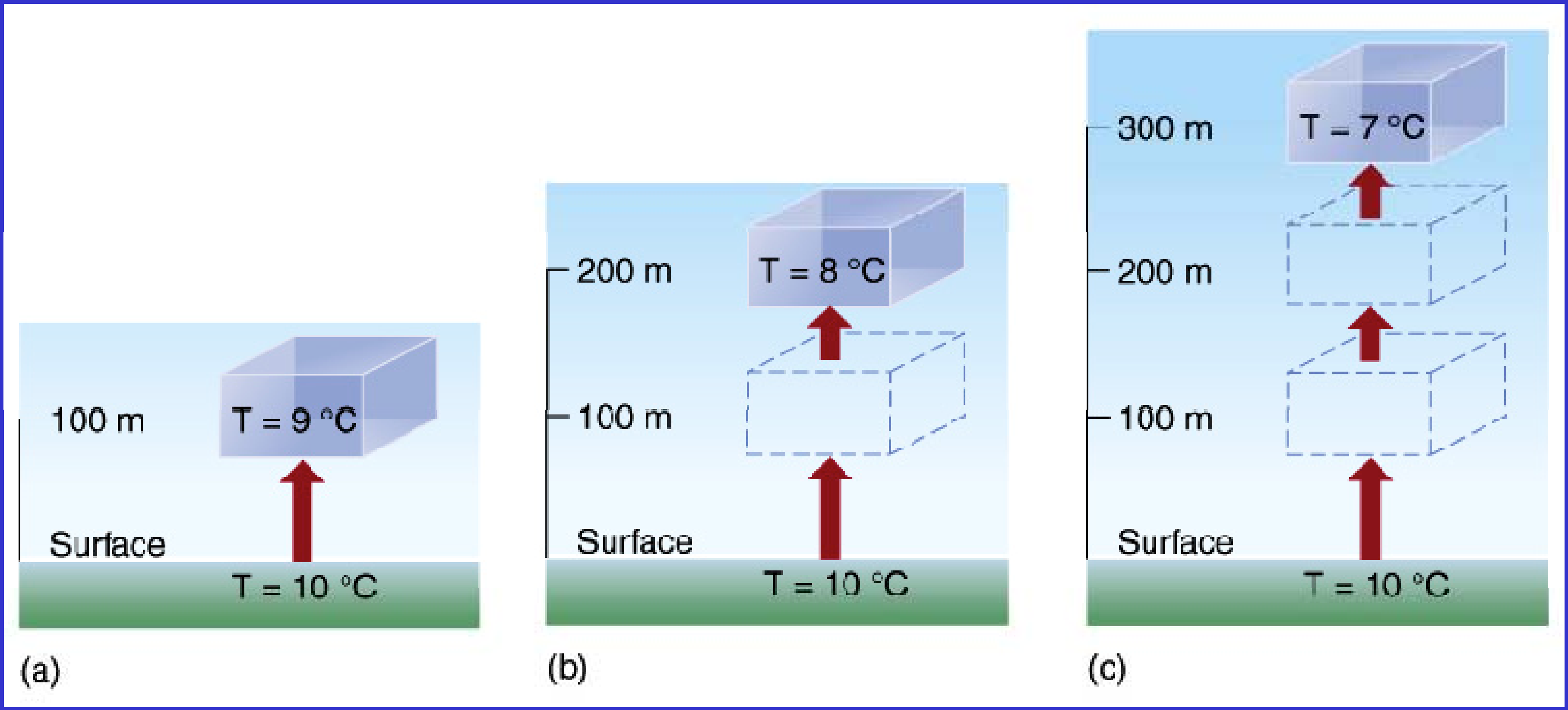
- 3 different lapse rates we need to consider:

(1) dry adiabatic lapse rate

(2) moist adiabatic lapse rate

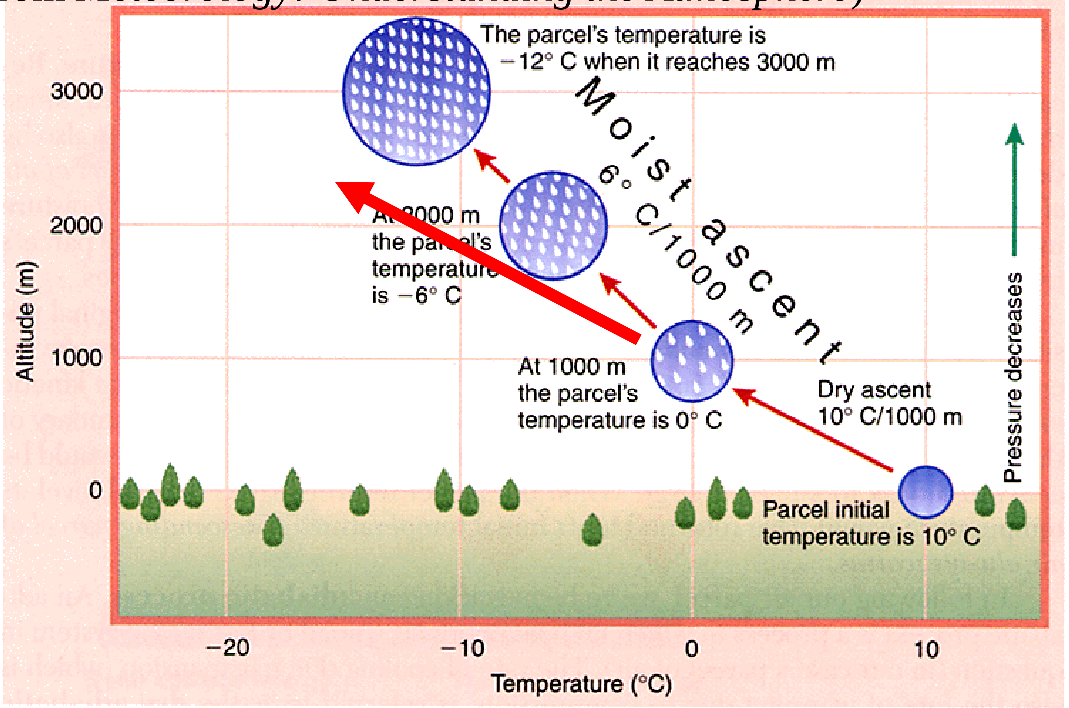
(3) environmental lapse rate

Dry Adiabatic Lapse Rate



Moist Adiabatic Lapse Rate

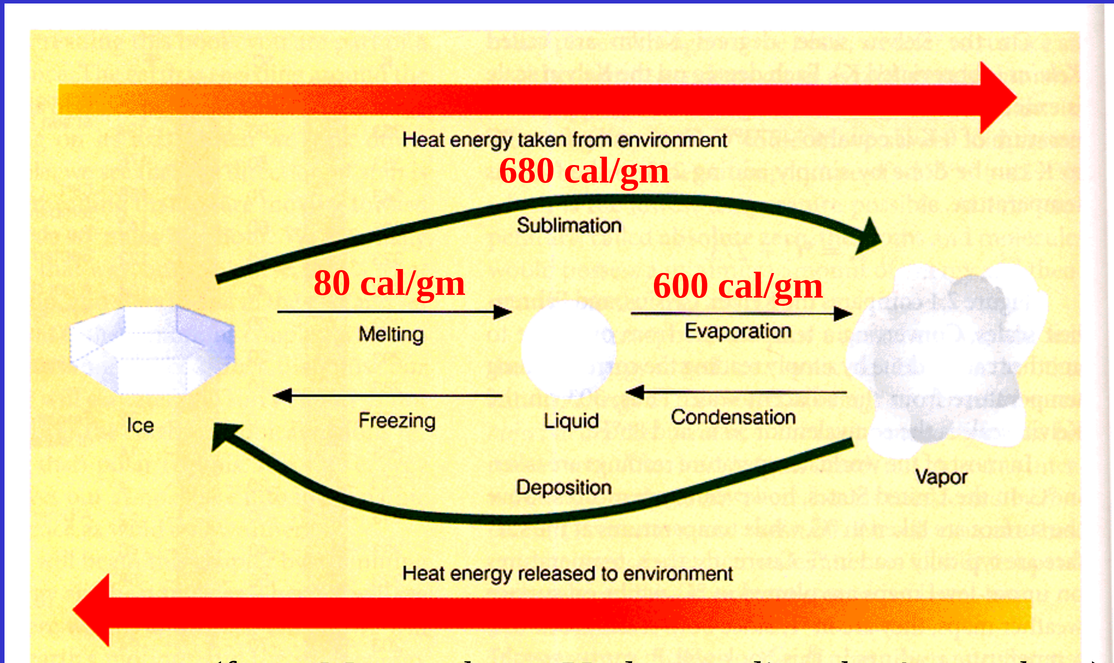
(from *Meteorology: Understanding the Atmosphere*)



- Air parcels that get saturated as they rise will cool at a rate smaller than the dry adiabatic lapse rate due the heating produced by the condensation of water vapor.
- This moist adiabatic lapse rate is not a constant but determined by considering the combined effects of expansion cooling and latent heating.

- In the lower troposphere, the rate is 10°C/km – 4°C/km = 6°C/km.
- In the middle troposphere, the rate is 10°C/km – 2°C/km = 8°C/km.
- Near tropopause, the rate is 10°C/km – 0°C/km = 10°C/km.

Phase Changes of Water



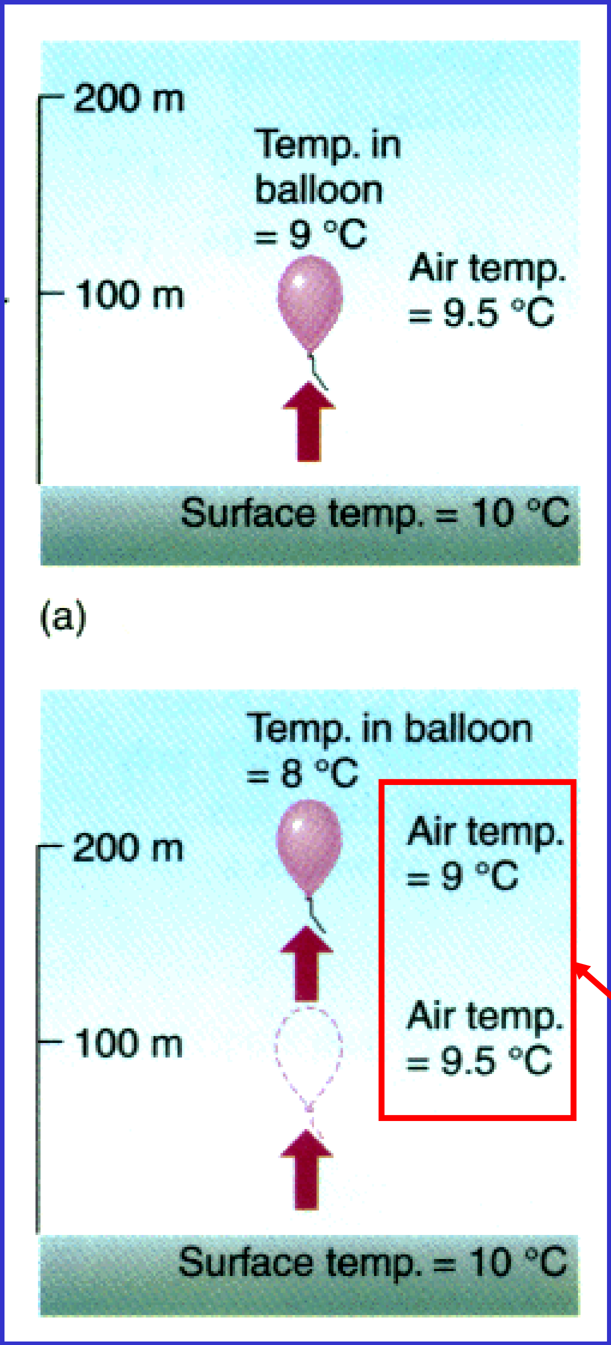
(from *Meteorology: Understanding the Atmosphere*)

- Latent heat is the heat released or absorbed per unit mass when water changes phase.
- Latent heating is an efficient way of transferring energy globally and is an important energy source for Earth's weather and climate.

Environmental Lapse Rate

- The environmental lapse rate is referred to as the rate at which the air temperature surrounding us (or the air parcels) would be changed if we were to climb upward into the atmosphere.
- This rate varies from time to time and from place to place.
- A rawinsonde's thermometer measures the environmental lapse rate.

Environmental Lapse Rate

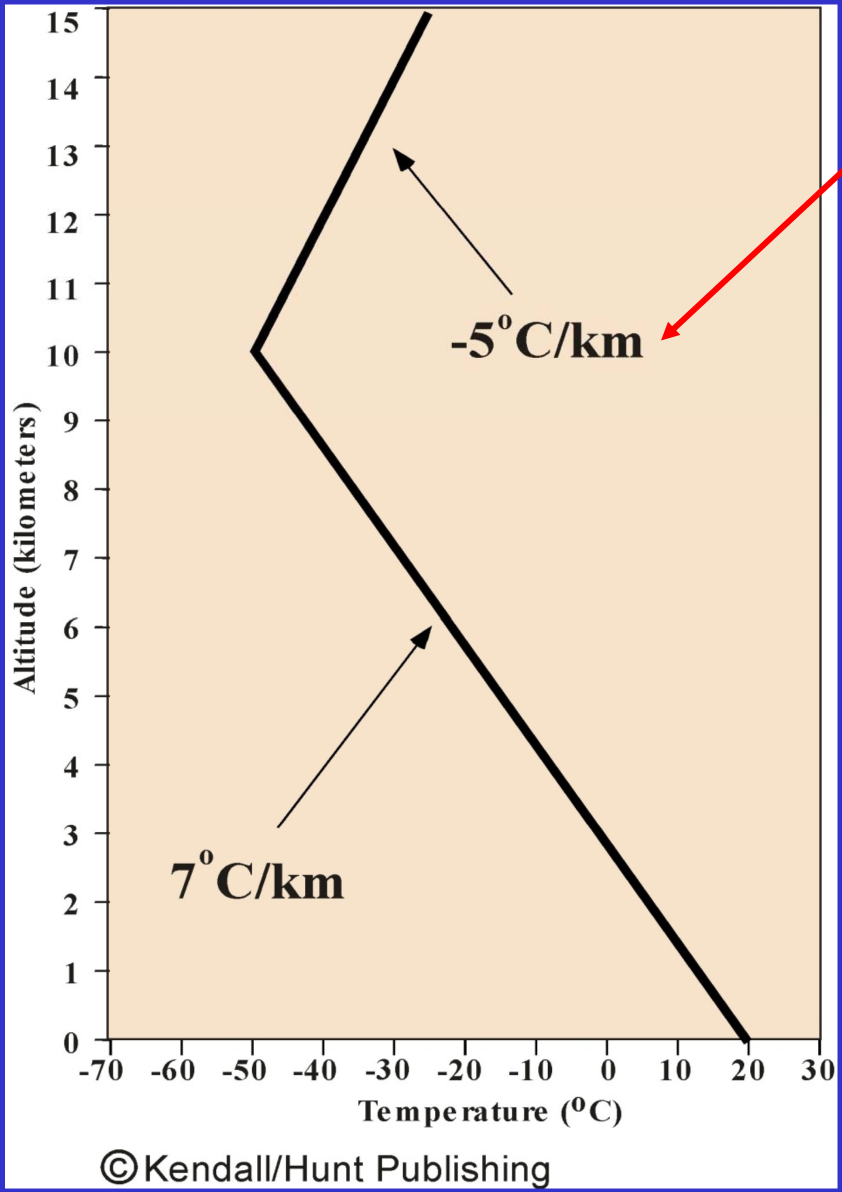


- The environmental (or ambient) lapse rate is referred to the vertical change in temperature through still air.
- The environmental lapse rate is not fixed. It changes from day to day and from place to place.

environmental lapse rate =0.5˚C/100m

(from *Understanding Weather & Climate*)

An Example of Environmental Lapse rate



Negative lapse rate is an inversion

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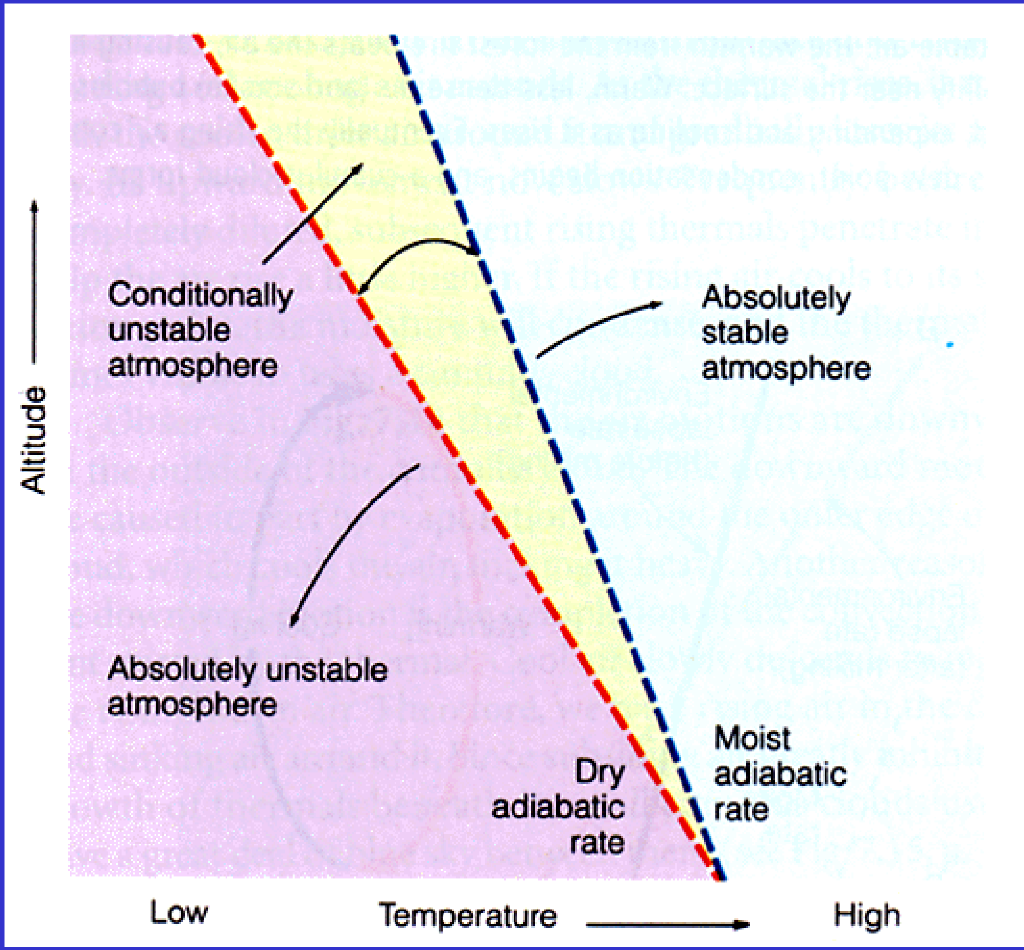
How to Determine Stability

- How do we determine where the atmosphere is unstable – under which convective clouds and storms may form?

➔ ***Answer***: Compare the environmental lapse rate with the dry/moist lapse rate

Static Stability of the Atmosphere



(from *Meteorology Today)*

Γe = environmental lapse rate

Γd = dry adiabatic lapse rate

Γm = moist adiabatic lapse rate

- Absolutely Stable

  $\Gamma e < \Gamma m$

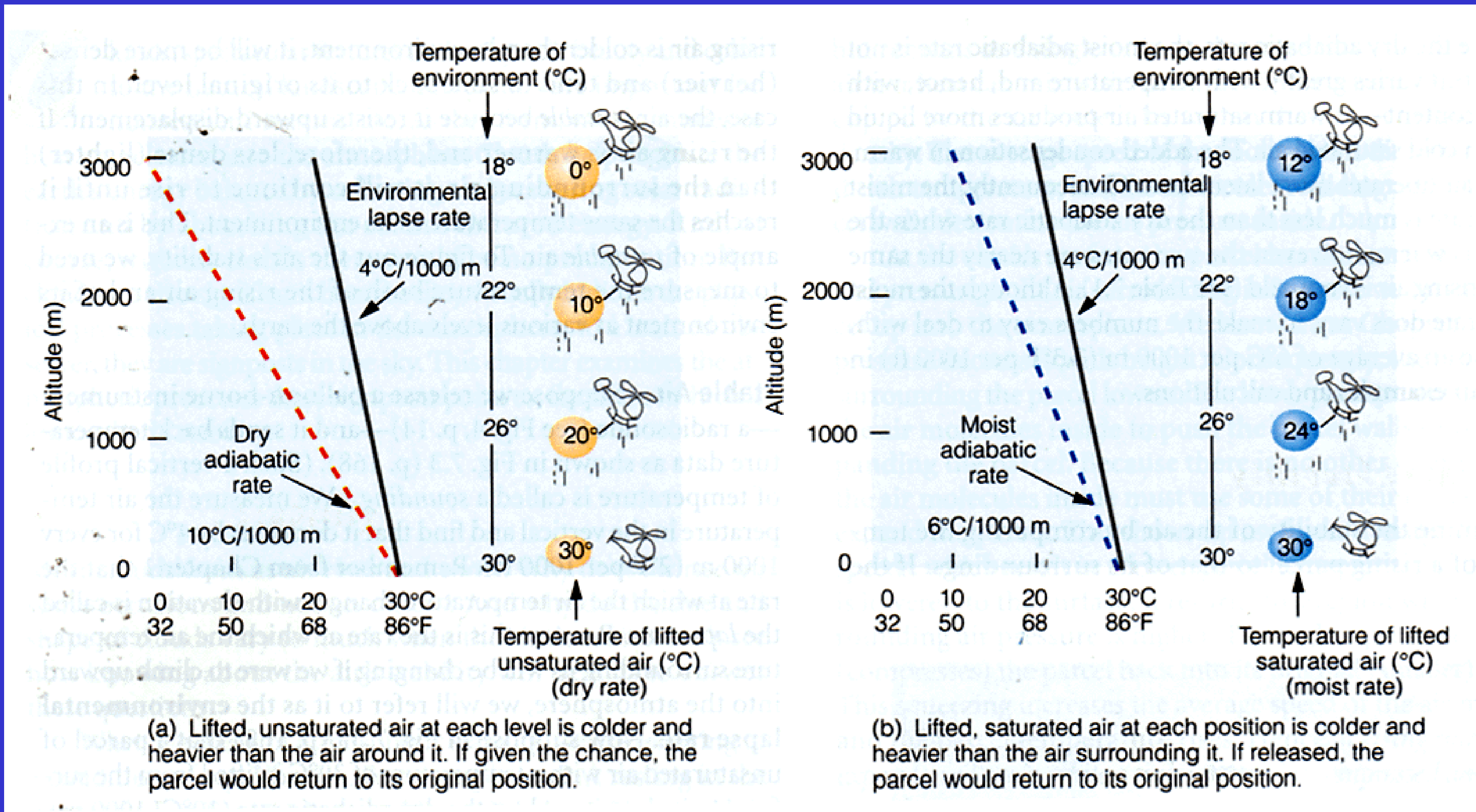
- Absolutely Unstable

  $\Gamma e > \Gamma d$

- Conditionally Unstable

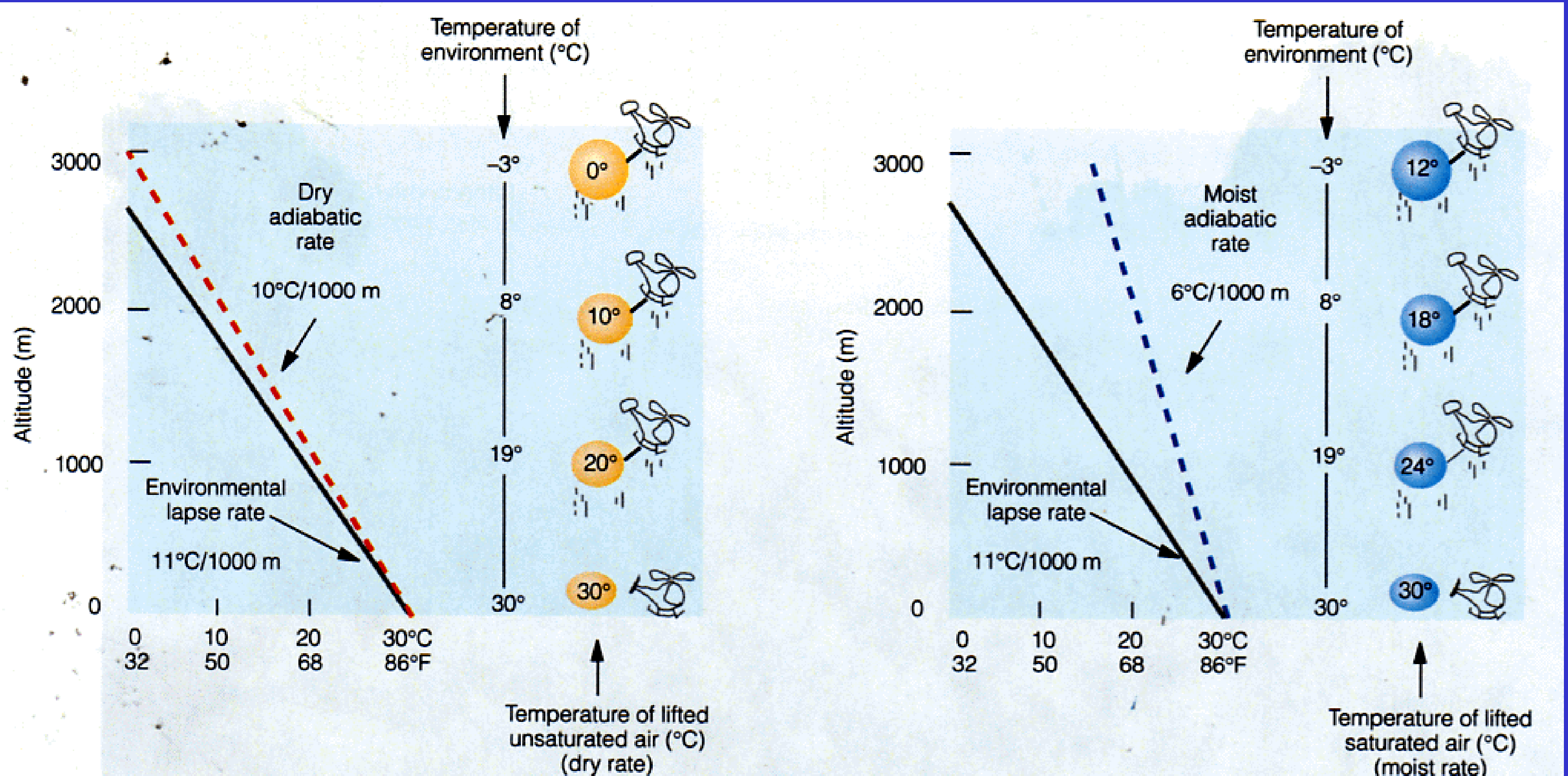
  $\Gamma m < \Gamma e < \Gamma d$

Absolutely Stable Atmosphere



(from *Meteorology Today*)

Absolutely Unstable Atmosphere



(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.

(from *Meteorology Today)*

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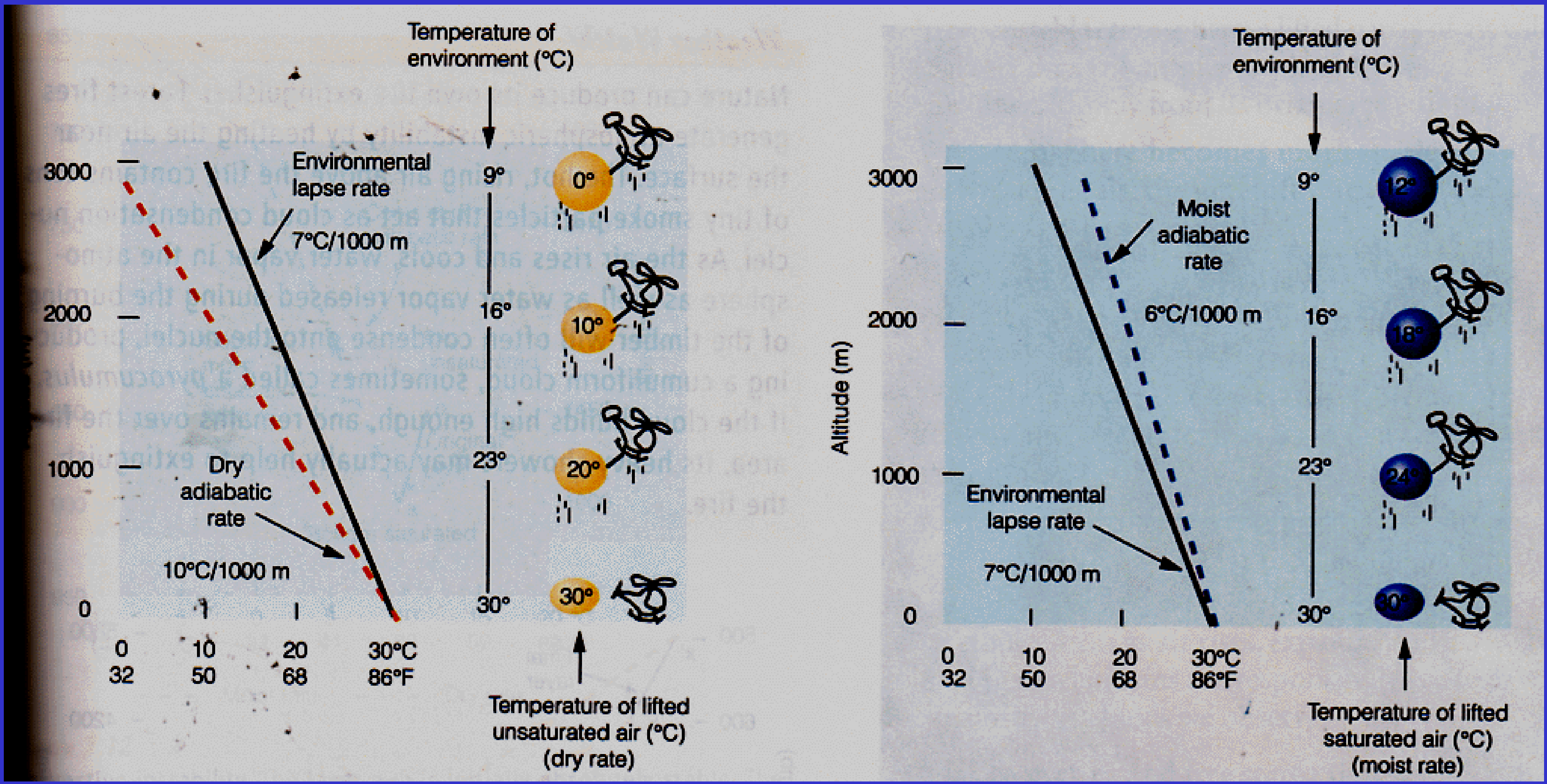
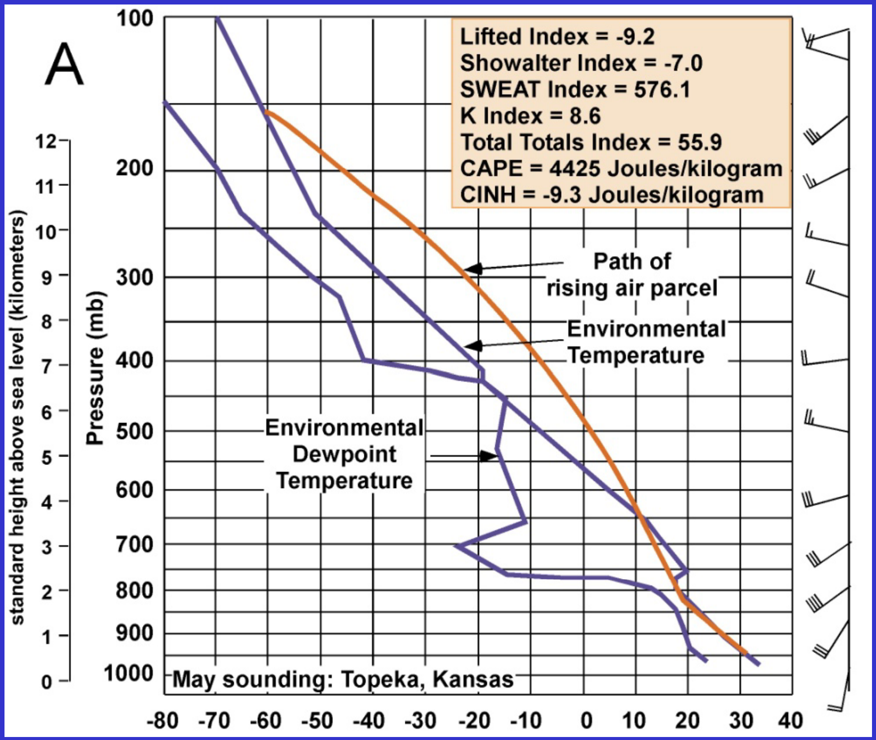
Conditionally Unstable Atmosphere



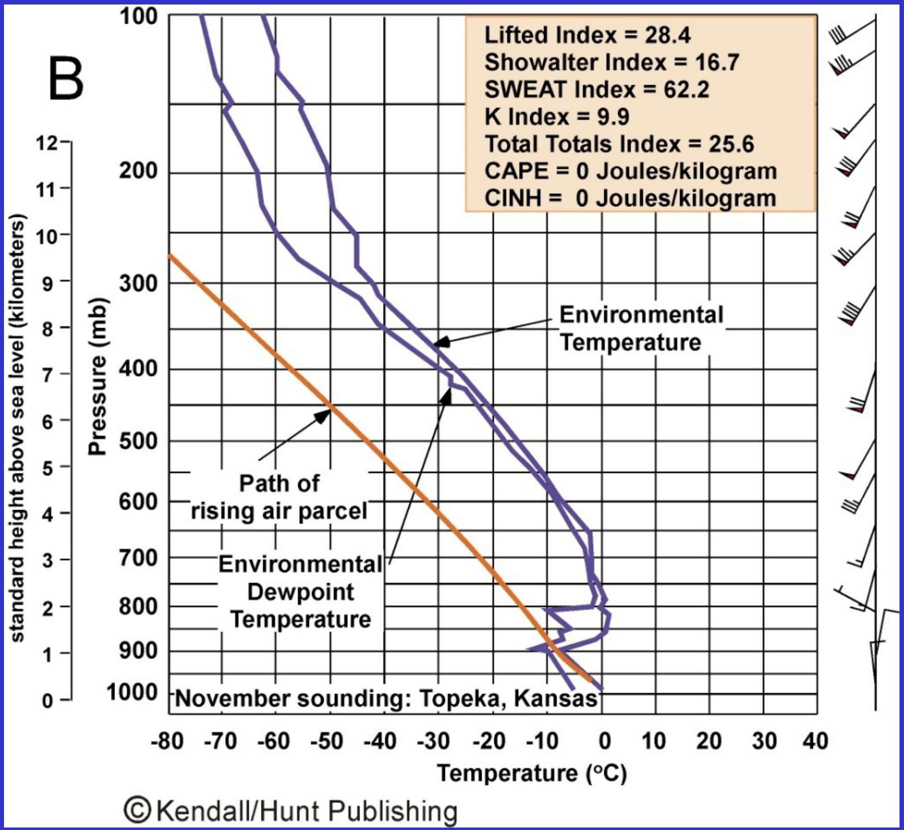
(from *Meteorology Today*)

Real-Life Examples in Topeka, Kansas

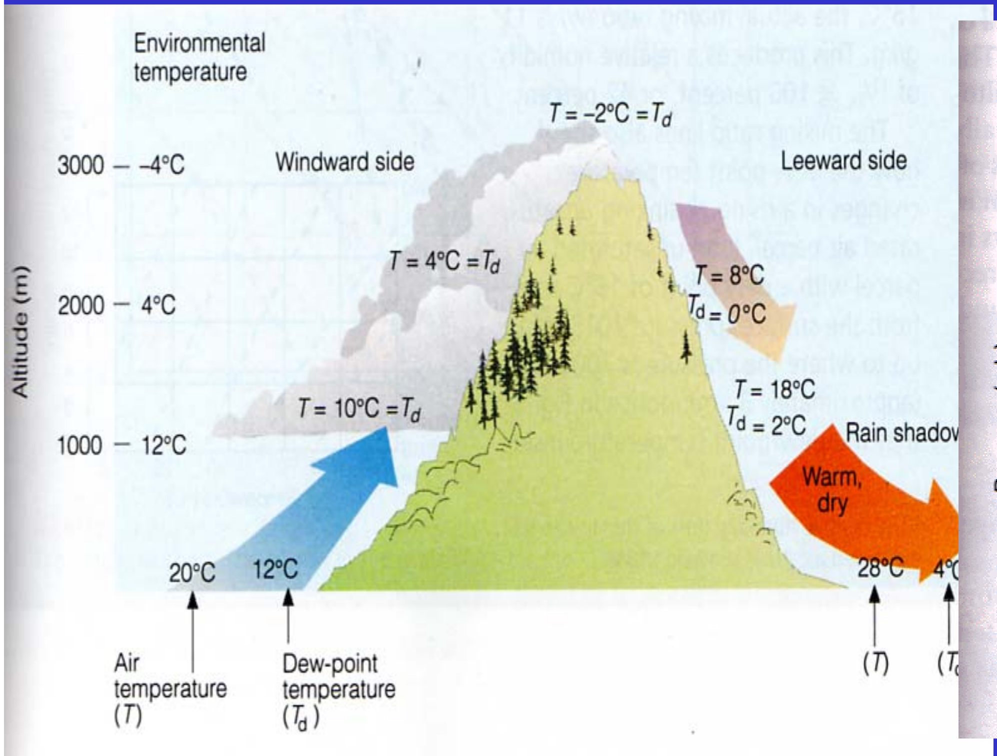
Unstable Atmosphere (May)



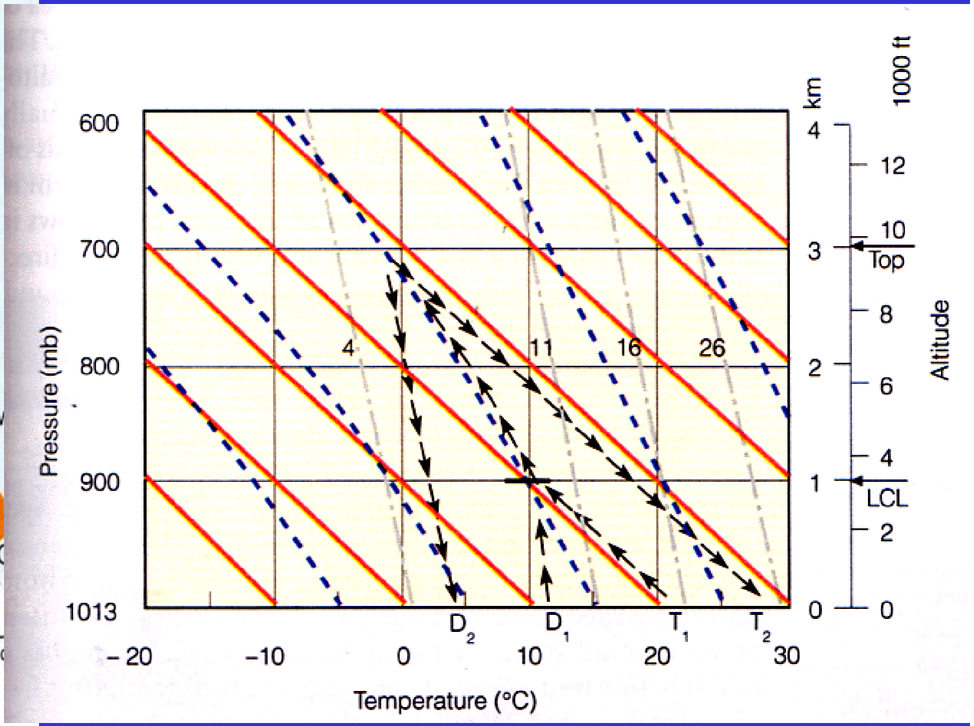
Stable Atmosphere (November)



An Example

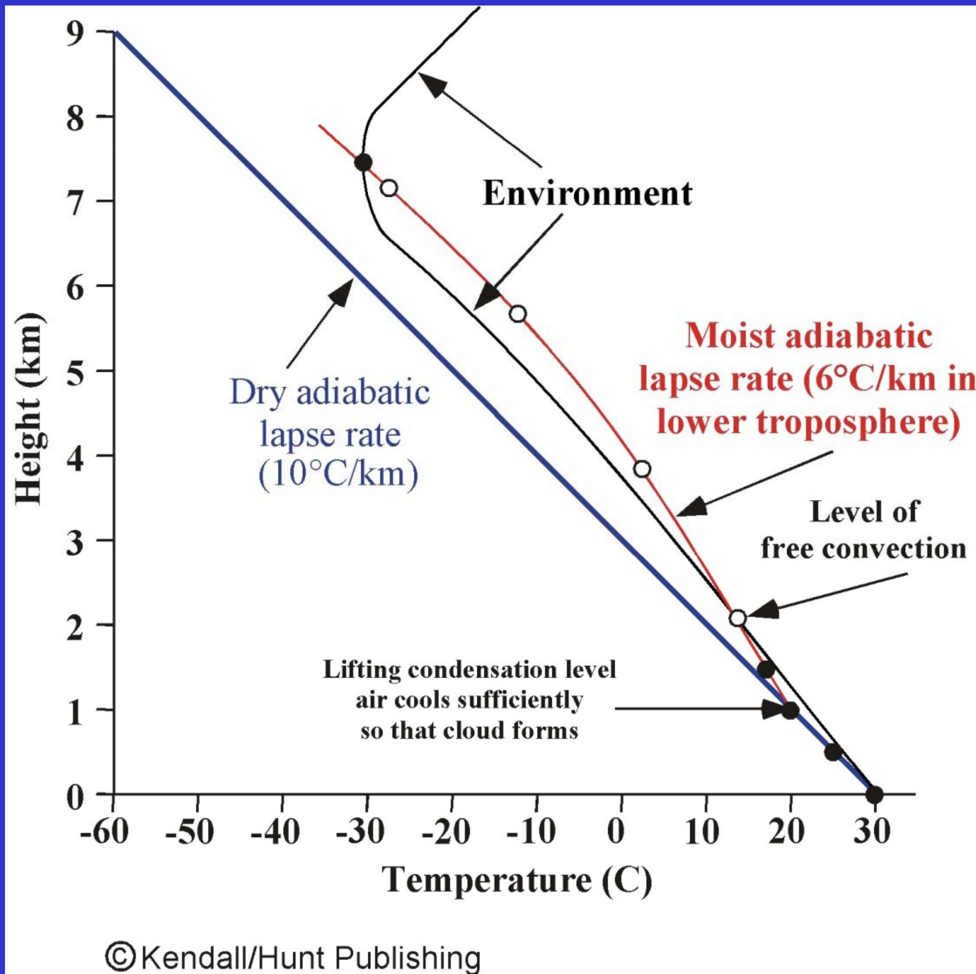


Environmental temperature
Altitude (m)
3000 — -4°C
2000 — 4°C
1000 — 12°C
Windward side
Leeward side
T = -2°C = Td
T = 4°C = Td
T = 10°C = Td
T = 8°C
Td = 0°C
T = 18°C
Td = 2°C
Rain shadow
Warm, dry
20°C
12°C
28°C
Air temperature (T)
Dew-point temperature (Td)
(T)



Pressure (mb)
600
700
800
900
1013
4
11
16
26
D2
D1
T1
T2
– 20
–10
0
10
20
30
Temperature (°C)
km
4
3
2
1
0
1000 ft
12
10
Top
8
6
4
LCL
2
0
Altitude

How Thunderstorm Forms?



- ***<u>Condensation Level</u>***

  where saturation first occurs and where cloud base is formed.

- ***<u>Lifting Condensation Level</u>***

  if the air is lifted to reach the condensation.

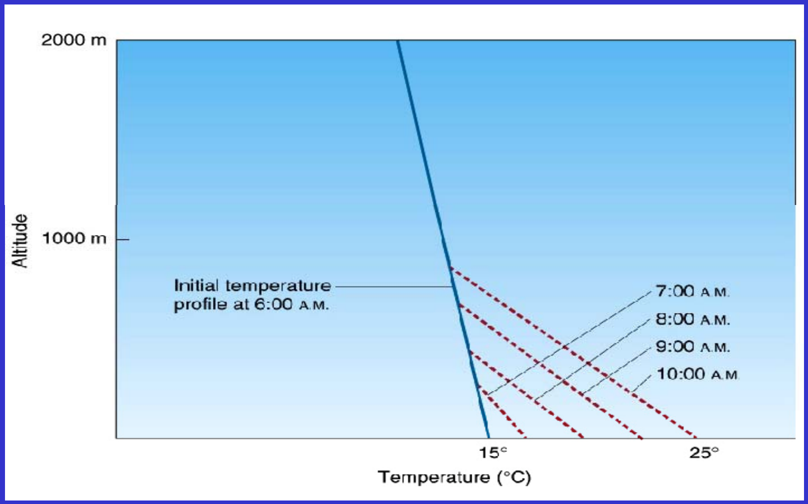
- ***<u>Level of Free Convection</u>***

  where the air first becomes buoyant (its temperature first exceeds the surrounding environment's temperature)

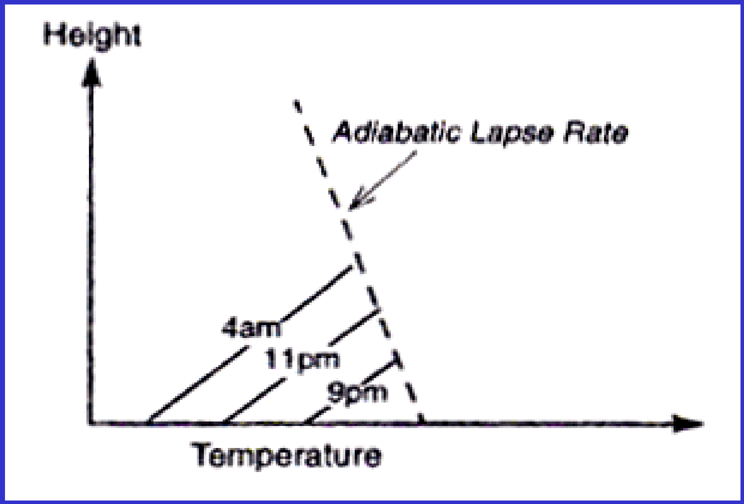
- Airs pass the level of free convection can form thunderstorms.

How to Change Environmental Lapse Rate?

Daytime



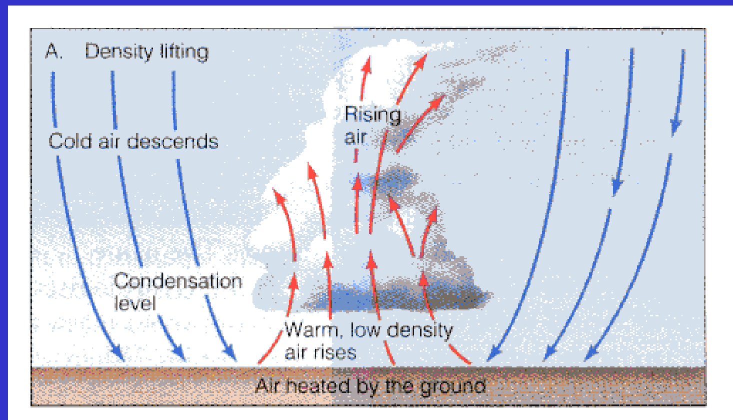
Nighttime



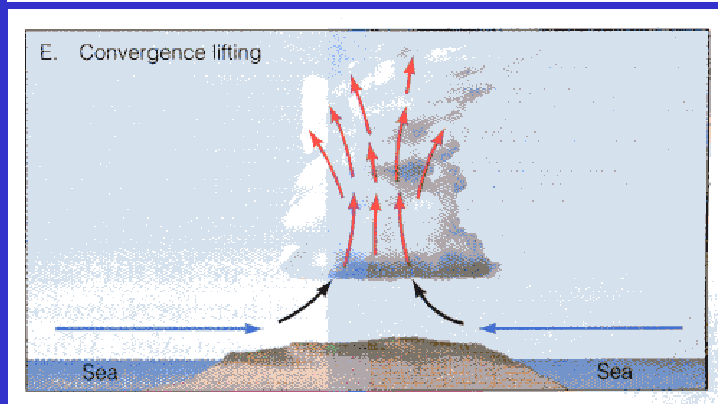
- During the day, surface insolation gains result in greater heating near the surface than aloft.
- At night, the situation reverses as terrestrial radiation loss causes near surface chilling → a ***temperature inversion.***

Four Ways to Lift Air Upward

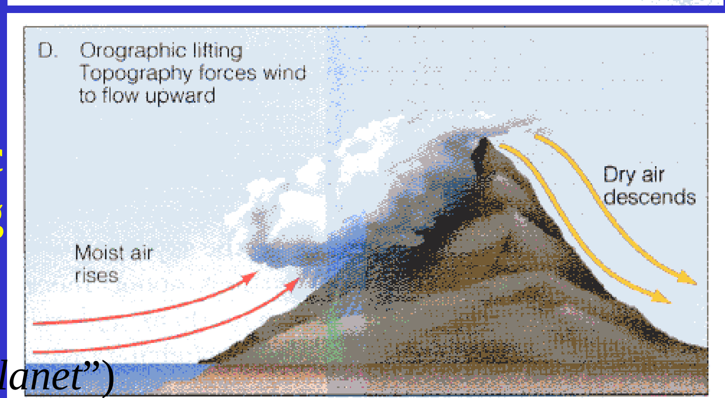
(1) Localized Convection



(2) Convergence Lifting



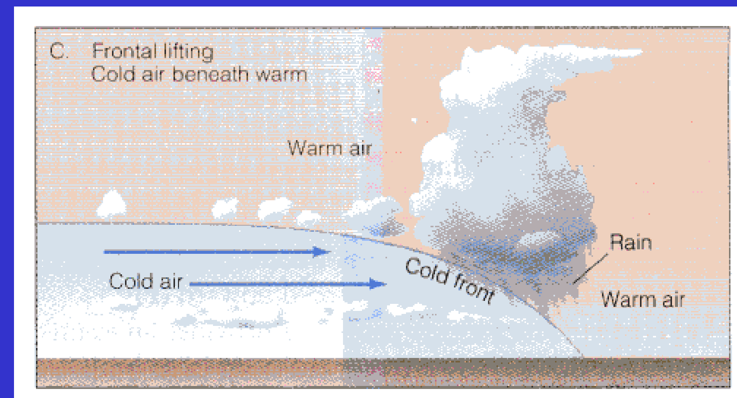
(3) Orographic Lifting



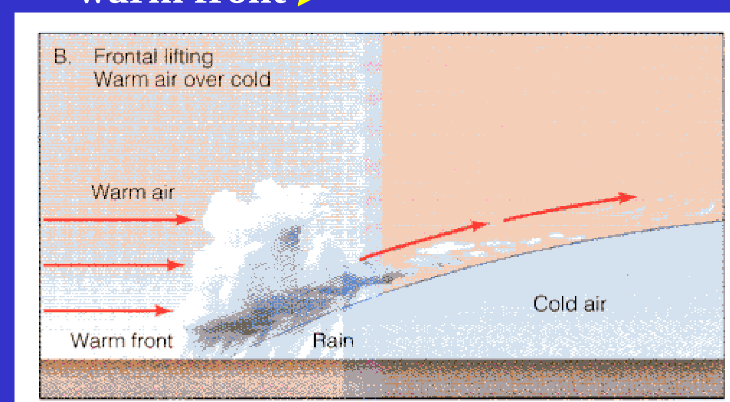
(from "*The Blue Planet*")

(4) Frontal Lifting

cold front



warm front



Stability Indices

(1) Environmental Lapse rate

(2) Lifted Index = T (environment at 500mb) – T (parcel lifted to 500mb)

(3) Showalter Index: similar to lifted index but was lifted to 850mb

(4) CAPE (Convective Available Potential Energy): derived from soundings

(5) Convective INHibition (CINH) Index

(6) K Index

(7) Total Totals Index

(8) SWEAT (Severe Weather Threat) Index

TABLE 6.2 **Stability Categories and Likelihood of Severe Convective Storms for Various Ranges of the Lifted Index (LI), Showalter Index (SI), Convective Available Potential Energy (CAPE), Total Totals (TT) Index and SWEAT (SW) Index**

Stability	LI	SI	CAPE	TT	SW
Very stable (no significant activity)	> +3				
Stable (Showers possible; T'showers unlikely)	0 to +3	> +2	<0		
Marginally unstable (T'showers possible)	–2 to 0	0 to 2	0 to 1000	45 to 50	
Moderately unstable (Thunderstorms possible)	–4 to –2	–3 to 0	1000 to 2500	50 to 55	250 to 300
Very unstable (Severe T'storms possible)	–6 to –4	–6 to –3	2500 to 3500	55 to 60	300 to 400
Extremely unstable (Severe T'storms probable; tornadoes possible)	< –6	< –6	> 3500	60	> 400