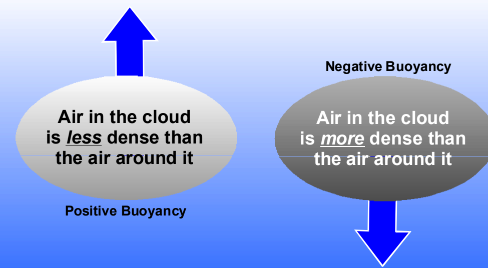
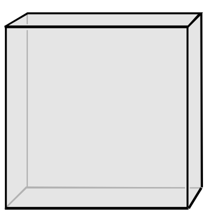
STABILITY

MET 3003
Lecture 9 14FEB06

Buoyancy



To understand buoyancy we need to think about a “***Parcel***” of air



- A cube 1 m^3 (for example)
- Weighs about 1.2 kg at 1013 mb and 288K
- As we have seen, density, ρ, is a function of “state variables”.
- These are: pressure, *p*, temperature, *T*, and water “mixing ratio,” *q*.
- The *p* and *T* normally decrease with height, both inside and outside clouds

We calculate density from the state variables with the Gas law for air

$$\frac{p}{\rho} = R_d T, \quad \rho = 1.22 \text{ kg m}^{-3}.$$

$$\text{for } T = 15^\circ\text{C}, \quad \text{and } p = 1013 \text{ mb}$$

R_d is the gas constant for dry air

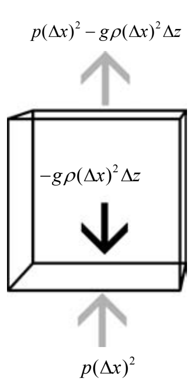
$$\equiv R^* / m_d = 287 \text{ J kg}^{-1}\ {}^\circ\text{C}^{-1}\ .$$

Hydrostatic Pressure

Pressure is the weight of air above. Taking the difference between pressure at top and bottom:

$$\frac{p_{\text{top}} - p_{\text{bottom}}}{\Delta z} = -g\rho = -\frac{gp}{R_d T},$$

using the gas law to get density.



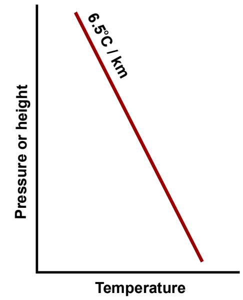
Remember Latent Heat

- When water evaporates (or ice melts) it absorbs heat
- When vapor condenses (or water freezes) it releases heat
- Called “Latent Heat” of condensation (or of freezing)
- Condensation of 1 gm of vapor in a kg or dry air releases enough heat to warm the air 2.5°C (2.834°C for deposition).
- Evaporation of 1 gm of liquid cools the air by 2.5°C (2.834°C for sublimation).

Other Forms of Energy

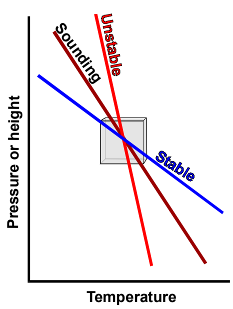
- Sensible heat: increase or decrease in temperture
- Work: A force acting through a distance
  - When a parcel expands is does work against the pressure in its surroundings
  - When a parcel shrinks the surroundings do work on the parcel
- Heat addition or removal (by Conduction or Radiation)
  - Absorption of visible or infrared radiation
  - Contact with warm or cool surface
  - Mixing (not considered here0
- "Adiabatic" means no heat added or removed
- Sensible heating, latent heating, and work all happen as the parcels move and evolve.

Lapse Rate



- Temperature normally decreases with height
- 6.5°C/km in standard atmosphere
- Again "**lapse rate**" means the *decrease* of temperature with height
- Negative lapse rate is an increase of temperature with height
- Or, an "inversion".

Environmental Lapse Rate or "Sounding"

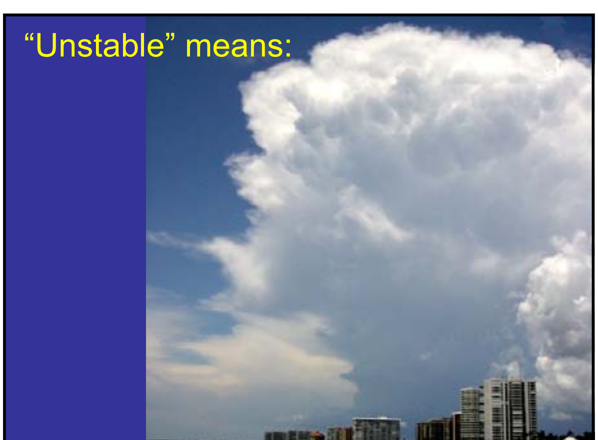


- Lapse rate measured by balloon is called the "**sounding**"
- Determines stability
- If the sounding lapse rate is greater than the lapse rate following a parcel, it is **unstable**.
- If the sounding lapse rate is less than the lapse rate following a parcel, it is **stable**.

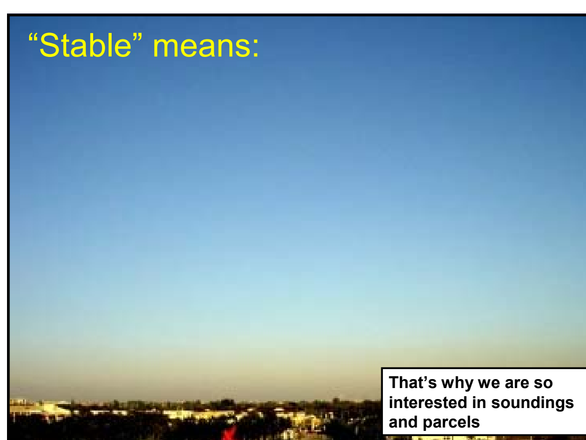
Explanation of Stability

- In a stable sounding:
  - A parcel displaced upward is cooler than its surroundings
  - Negatively buoyant
  - And returns to its original level
  - A parcel displaced downward is warmer than its surroundings, positively buoyant and returns to its original level
- In an unstable sounding:
  - A parcel displaced upward is warmer than its surroundings
  - Positively buoyant
  - And accelerates away from its original level
  - A parcel displaced downward is cooler than its surroundings, negatively buoyant and accelerates away from its original level
- In a neutral sounding
  - Displaced parcels have the same temperature as their surroundings and stay at their new location

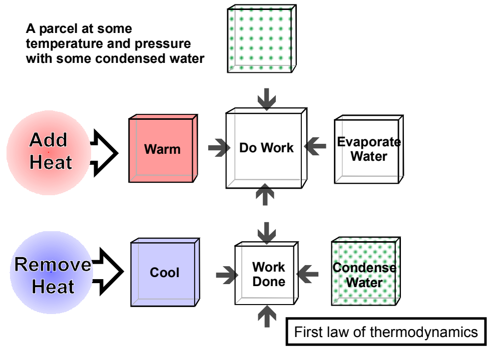
"Unstable" means:



"Stable" means:



No energy can be created or destroyed



Or Mathematically

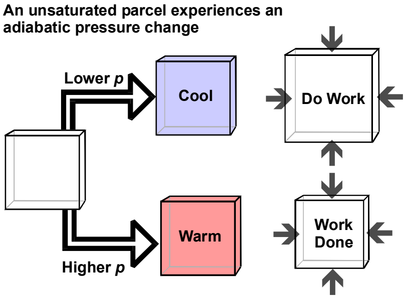
$$\Delta Q = c_v \Delta T + P\Delta\alpha + L\Delta q$$

or

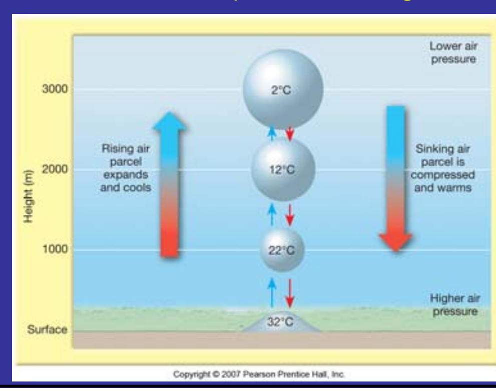
$$\Delta Q = c_p \Delta T - \alpha\Delta P + L\Delta q$$

Dry Adiabatic Process

An unsaturated parcel experiences an adiabatic pressure change

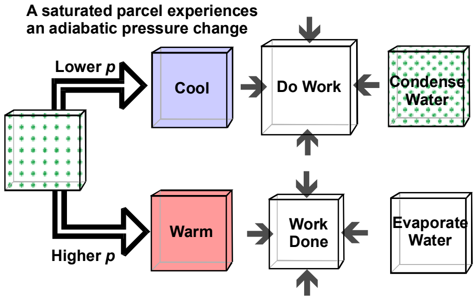


Adiabatic Temperature Changes

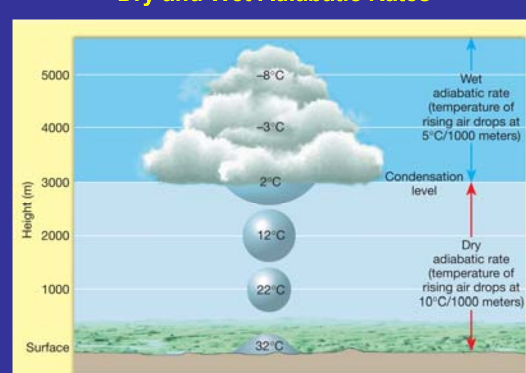


Moist Adiabatic Process

A saturated parcel experiences an adiabatic pressure change



Dry and Wet Adiabatic Rates



Analysis

Dry Adiabatic

$$c_p \frac{\Delta T}{\Delta z} = \alpha \frac{\Delta p}{\Delta z} = \alpha(-g\rho) = -g \text{ or } -\frac{\Delta T}{\Delta z} = \frac{g}{c_p} = 9.8^{\circ}\text{C km}^{-1}$$

Moist Adiabatic

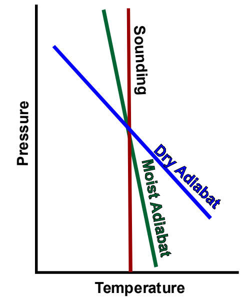
$$c_p \frac{\Delta T}{\Delta z} + L\frac{\Delta q}{\Delta z} = -g$$

$$c_p \frac{\Delta T}{\Delta z} + L\frac{\Delta q}{\Delta T}\frac{\Delta T}{\Delta z} = -g - L\frac{\Delta q}{\Delta p}\frac{\Delta p}{\Delta z} = -g + L\frac{\Delta q}{\Delta p} g\rho$$

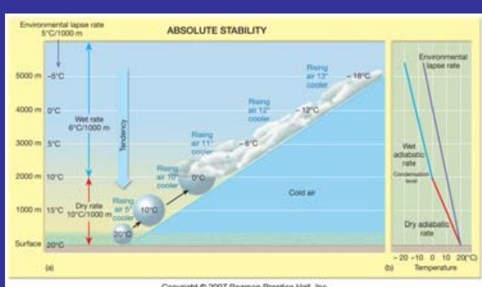
$$c_p \frac{\Delta T}{\Delta z}\left(1 + \frac{L}{c_p}\frac{\Delta q}{\Delta T}\right) = -g\left(1 - \rho L\frac{\Delta q}{\Delta p}\right) \text{ or } -\frac{\Delta T}{\Delta z} = \frac{g}{c_p}\frac{1-\rho L\frac{\Delta q}{\Delta p}}{1+\frac{L}{c_p}\frac{\Delta q}{\Delta T}} < \frac{g}{c_p}$$

Absolute Stability

- Sounding lapse rate less than either moist or dry adiabatic
- Always stable
- Cool clear days in the winter or over cool water
- Often caused by synoptic-scale sinking
- Includes inversions

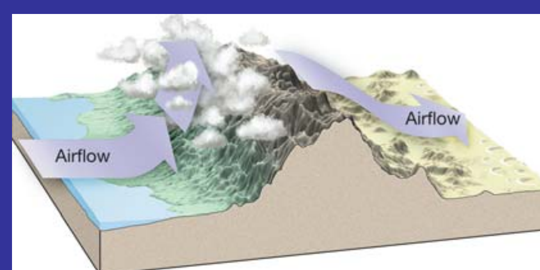


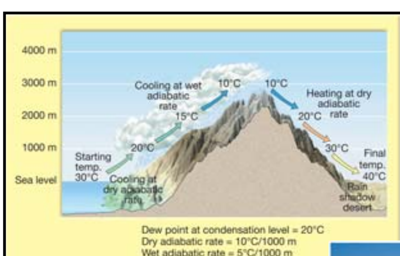
Atmospheric Stability



Absolute Stability

Example Orographic Lifting Processes





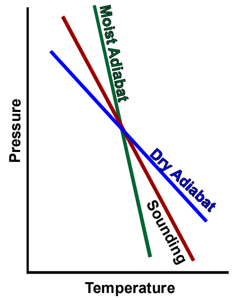
Death Valley

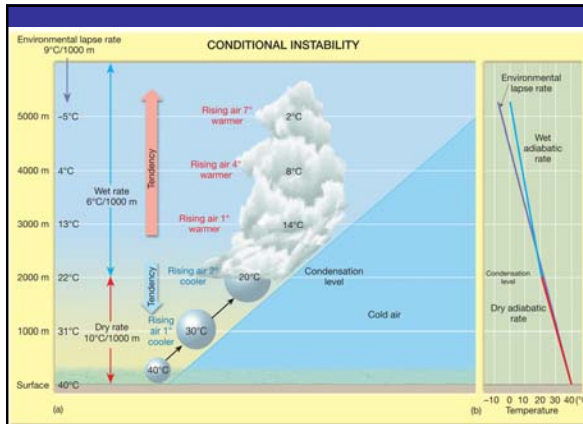
Rain Shadow Desert

Frontal Wedging

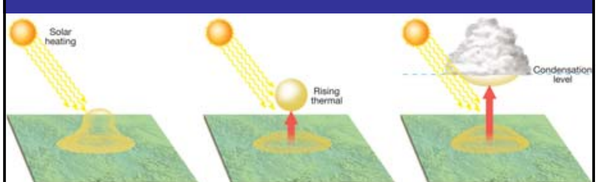
Conditional Instability

- Sounding lapse rate between moist and dry adiabatic
- Moist is unstable
- Dry is stable
- Common
- Depends upon the ***condition*** (saturated or not)



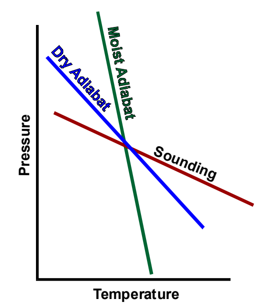


Convection

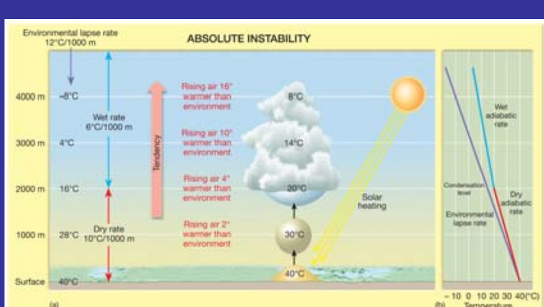


Absolute Instability

- Sounding lapse rate greater than either moist or dry adiabatic
- Always unstable
- Rare
- Hot days in the desert or over very warm water in light winds

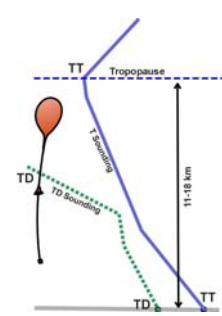


Absolute Instability



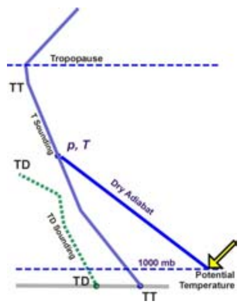
Observing Atmospheric Soundings with RAWINSONDEs

- Weather balloons
- Released worldwide at 00 and 12 GMT (7 AM & 7PM EST)
- Vertical profiles of
  - Temperature
  - Dew Point
  - Wind
- From surface to strato-sphere (20-30 km)
- ~90 Stations in US

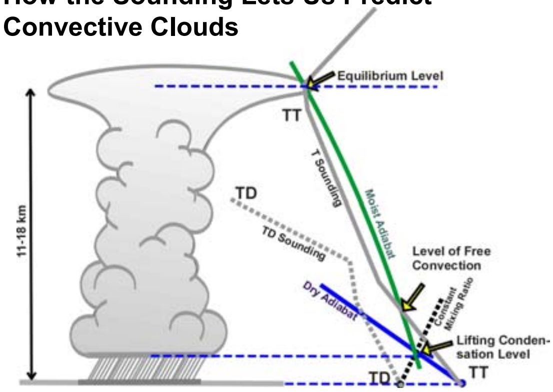


Potential Temperature

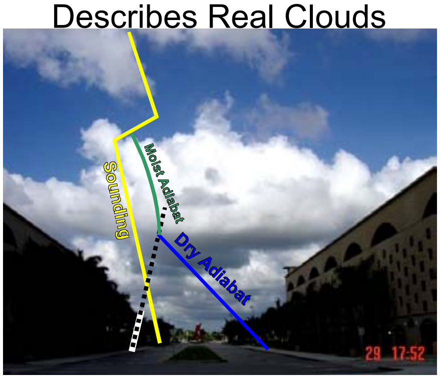
- Temperature where a dry adiabat starting from the sounding reaches 1000 mb
- Equivalent Potential Temperature.
  - Convert latent heat to sensible (2.5ºC per gm kg^{-1})
  - Connect from resulting temp, to 1000 mb on a dry adiabat
  - Always greater than potential temperature
- Potential Temperatures and Stability
  - Absolute stability: Both potential temperature (θ) and equivalent potential (θ_e) increase with height
  - Conditional instability θ increases but θ_e decreases
  - Absolute instability θ decreases with height



How the Sounding Lets Us Predict Convective Clouds



How Parcel Thermodynamics Describes Real Clouds



Summary (1)

- Understand ***Buoyancy***
- Understand the ***Parcel*** concept and the role of denisty in buoyancy
- Be able to define an ***Adiabatic Process***
- Understand the roles in convection of
  - ***Latent Heat***
  - ***Sensible Heat***
  - ***Pressure work***
- Be able to define environmental (sounding) and parcel ***Lapse Rates***
- Understand ***Dry*** and ***Moist Adiabatic Processes***
- Understand
  - ***Absolute Stability***
  - ***Conditional Instability***
  - ***Absolute Instability***

Summary (2)

- Know the definitions of:
  - ***Potential Temperature (θ)***
  - ***Equivalent Potential Temperature (θ_e)***
- Be able to explain stability in terms of θ and θ_e
- Understand the structure of a convective cloud in terms or parcel thermodynamics
- Know the definitions of and be able to use
  - ***LCL***: Lifting Condensation Level (cloud base)
  - ***LFC***: Level of free convection
  - ***EL***: Equilibrium Level (cloud top)
- **Reading for next time: L&T Chapter 5**