The atmosphere’s water

Properties of Water

• Physical States
  – only natural substance that occurs naturally in three states on the earth’s surface
• Heat Capacity
  – Highest of all common solids and liquids
• Surface Tension
  – Highest of all common liquids
• Latent Heat of Fusion
  – Highest of all common substances
• Compressibility
  – Virtually incompressible as a liquid
• Density
  – Density of seawater is controlled by temperature, salinity and pressure
  – Liquid has maximum density at +4°C; solid phase has lower density!

Properties of Water (cont’)

• Radiative Properties
  – transparent to visible wavelengths
  – virtually opaque to many infrared wavelengths
  – large range of albedo possible
    • water 10 % (daily average)
    • Ice 30 to 40%
    • Snow 20 to 95%
    • Cloud 30 to 90%

Energy associated with phase change
Why does it take so much energy to evaporate water?

- In the liquid state, adjacent water molecules attract one another
  - “-” charge on O attracted to “+” charge on H
  - we call this hydrogen bonding
- This same hydrogen bond accounts for surface tension on a free water surface
  - column of water

Sublimation - evaporate ice directly to water vapor

Take one gram of ice at zero degrees centigrade

Energy required to change the phase of one gram of ice to vapor:

- Add 80 calories to melt the ice
- Add 100 calories to raise the temperature to 100 degrees C
- Add 540 calories to evaporate the liquid

Total Energy \textbf{ADDED} for sublimation of 1 gram of ice:

$$80 + 100 + 540 = 720 \text{ calories}$$

Deposition - convert vapor directly to ice

Take one gram of water vapor at 100 degrees Centigrade

- Release 540 calories to condense
- Release 100 calories to cool temperature of liquid to °C
- Release 80 calories to freeze water

Total energy \textbf{RELEASED} for deposition of 1 gram of ice

$$540 + 100 + 80 = 720 \text{ calories}$$

Water vapor pressure

- Molecules in an air parcel all contribute to parcel pressure
- Each subset of molecules (e.g., N$_2$, O$_2$, H$_2$O) exerts a partial pressure
- The VAPOR PRESSURE, $e$, is the pressure exerted by water vapor molecules in the air
  - similar to atmospheric pressure, but due only to the water vapor molecules
  - often expressed in mbar (2-30 mbar common at surface)
Water vapor saturation

- Water molecules move between the liquid and gas phases
- When the rate of water molecules entering the liquid equals the rate leaving the liquid, we have equilibrium
  - The air is said to be saturated with water vapor at this point
  - Equilibrium does not mean no exchange occurs

$e_s$ vs $T$ plot

- The saturation vapor pressure of water increases with temperature
  - At higher $T$, faster water molecules in liquid escape more frequently causing equilibrium water vapor concentration to rise
  - We sometimes say “warmer air can hold more water”
- There is also a vapor pressure of water over an ice surface
  - The saturation vapor pressure above solid ice is less than above liquid water

$e_s$ vs $T$ schematic

Saturation vapor pressure depends upon temperature

How do we express the amount of water vapor in an air parcel?

- Absolute humidity
  - mass of water vapor/volume of air (g/m$^3$)
  - changes when air parcel volume changes
- Specific humidity
  - mass of water vapor/mass of air (g/kg)
- Mixing ratio
  - mass of water vapor/mass of dry air (g/kg)
- Specific humidity and mixing ratio remain constant as long as water vapor is not added/removed to/from air parcel
- Dew point temperature
Expressing the water vapor pressure

- Relative Humidity (RH) is ratio of actual vapor pressure to saturation vapor pressure
  - $100 \times \frac{e}{e_S}$
  - Range: 0-100% (+)
  - Air with RH > 100% is supersaturated
- RH can be changed by
  - Changes in water vapor content, $e$
  - Changes in temperature, which alter $e_S$

Dewpoint Temperatures

- Dewpoint is a measure of the water vapor content of the air
- It is not a measure of temperature!

Which environment has higher water vapor content?

Water vapor is distributed throughout the atmosphere

- Generally largest amounts are found close to the surface, decreasing aloft
  - Closest to the source - evaporation from ground, plants, lakes and ocean
  - Warmer air can hold more water vapor than colder air
Fresh vs. salt water

- Most of the earth’s water is found in the oceans
- Only 3% is fresh water and 3/4 of that is ice
- The atmosphere contains only ~1 week supply of precipitation

Why is the southwest coast of the US hot and dry while the Gulf coast is hot and moist?

- Both are adjacent to large bodies of water
- Both experience onshore wind flow on a regular basis
- Why does one have a desert like climate and the other ample moisture and rainfall?