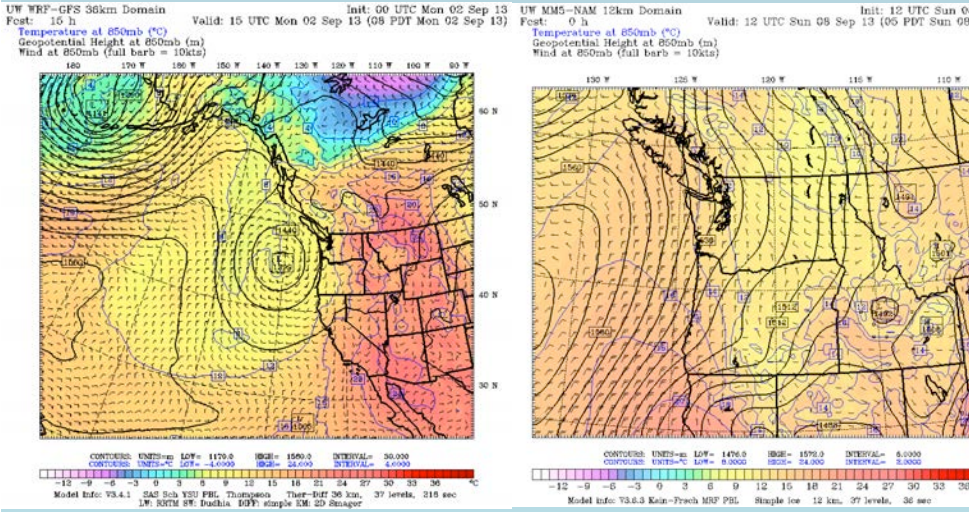
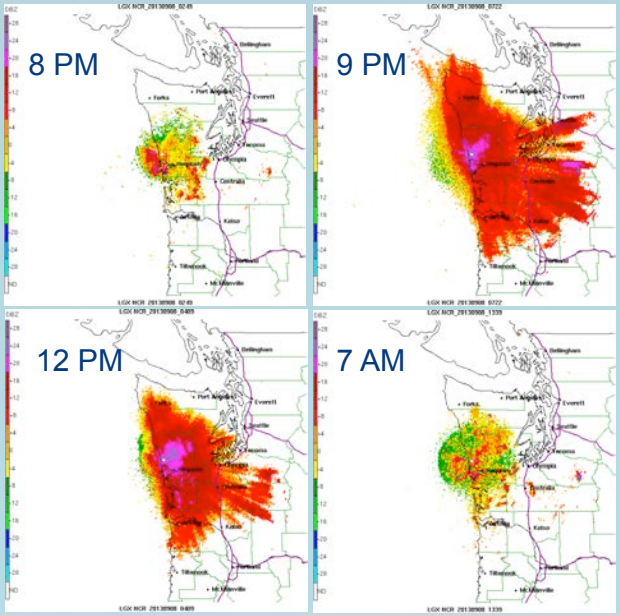
MET 200 Lecture 5: Water

Fall Weather and Birds

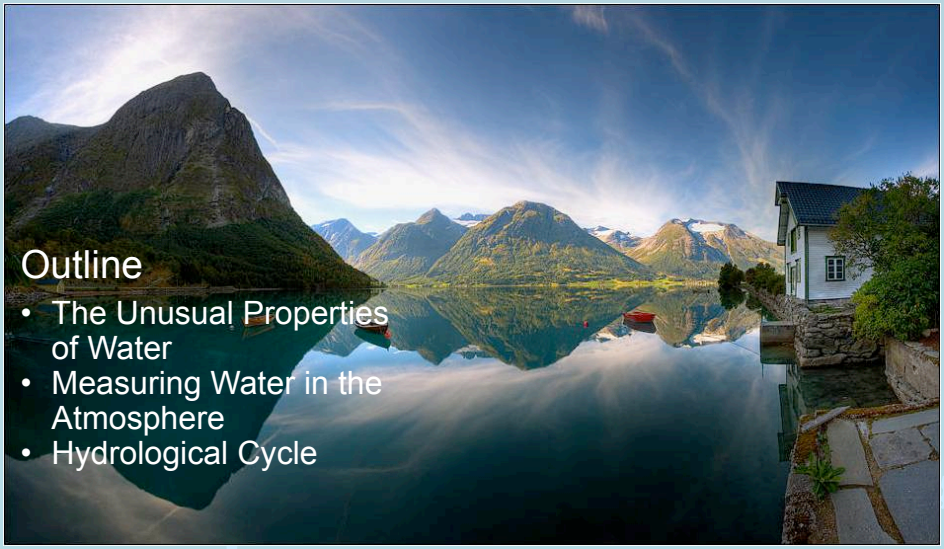


Radar Story



Previous Lecture
Seasons and Diurnal Cycle

Lecture 5 Water



Outline

- The Unusual Properties of Water
- Measuring Water in the Atmosphere
- Hydrological Cycle

The Importance of Water

Once, during Prohibition, I was forced to live for days on nothing but food and water. W. C. Fields

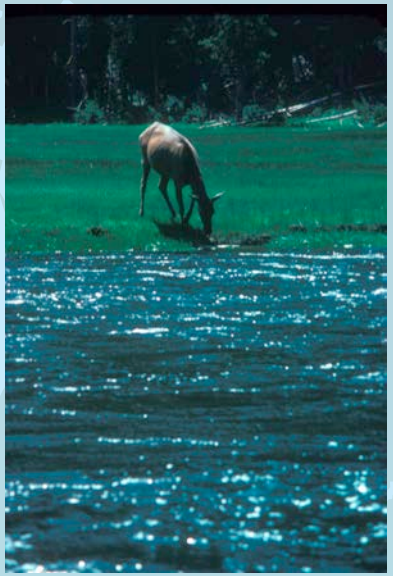
The Importance of Water

Nothing is softer or more flexible than water, yet nothing can resist it. Lao-Tzu (600 B.C.)

The Importance of Water

'Water is the driver of Nature' Leonardo da Vinci

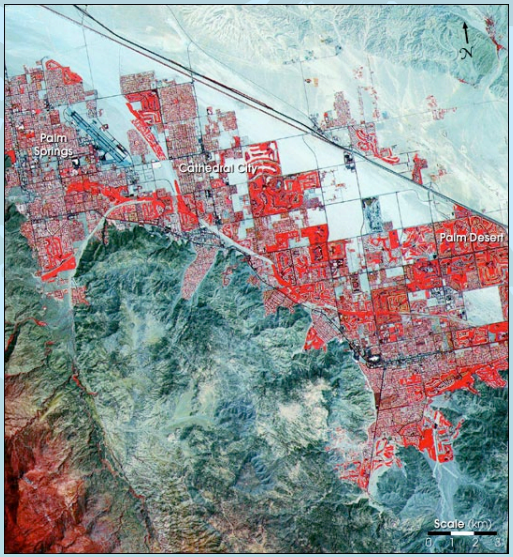
"We forget that the water cycle and the life cycle are one." Jacques Yves Cousteau



The Importance of Water

"Not all chemicals are bad. Without chemicals such as hydrogen and oxygen, for example, there would be no way to make water, a vital ingredient in beer." Dave Barry

The Importance of Water



The red color in this infrared image is vegetation.

Importance of Water (H_2O)

Three phases
Vapor: invisible
Liquid: cloud, rain
Ice, snow

Ice, hail

Clouds
✓Impact radiation
✓Release latent heat

Water drops

Rain

Ocean: heat storage and transport

Unusual Properties of Water

Radiative Properties

- transparent to visible wavelengths
- virtually opaque to many infrared wavelengths
- large range of albedos possible
  - water 10 % (daily average)
  - Ice 30 to 40%
  - Snow 20 to 95%
  - Cloud 30 to 90%

Unusual Properties of Water

Physical States
- only substance that occurs naturally in three states on the earth's surface

Heat Capacity
- Highest of all common solids and liquids

Latent Heats
- Highest of all common substances

For 1 gram of water,
- 100 calories to raise temperature from 0 to 100˚C
- 550 calories to evaporate
- 80 calories to melt ice

Unusual Properties of Water

Surface Tension
- Highest of all common liquids
- Capillary action

Density
- Liquid water has maximum density at +4˚C; solid phase has lower density.
- Ice floats on water! Water expands to occupy 9% greater volume in its solid state.

Compressibility
- Virtually incompressible as a liquid

Unusual Properties of Water

Surface Tension

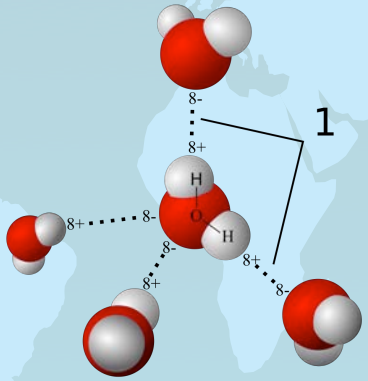
Unusual Properties of Water

Surface Tension

Unusual Properties of Water

Surface Tension – Water Strider

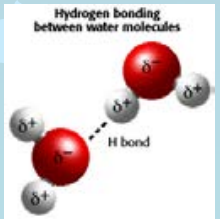
Why does it take so much energy to evaporate water?



Blame it on Hydrogen Bonds

Why does it take so much energy to evaporate water?

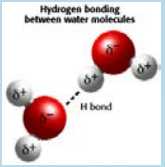
- In the liquid state, adjacent water molecules attract one another.
- Negative charge on oxygen is attracted to positive charge on hydrogen atom.
- We call this hydrogen bonding.
- Hydrogen bonds are uncommonly strong.



Impact of Hydrogen Bonds

The large amount of energy needed to break (and form) hydrogen bonds explains:

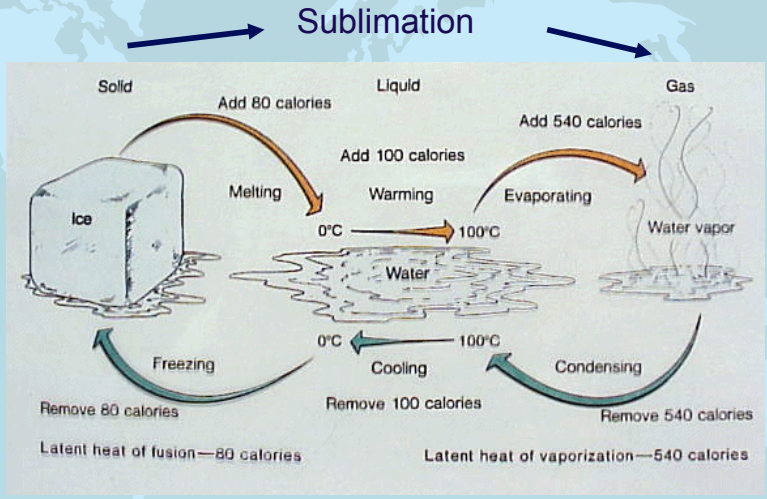
- The large latent heats associated with changes of state.
- The large heat capacity of water.
- The large surface tension on a free water surface.



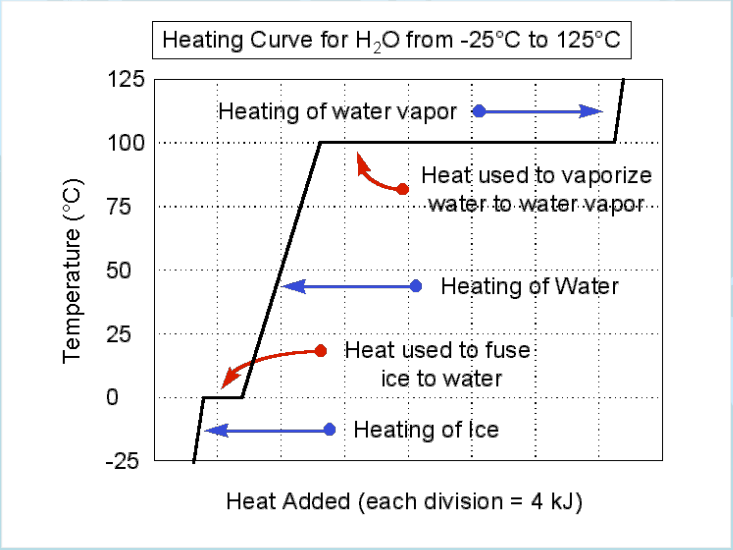
Lightning

The asymmetric charge distribution in water molecules results in a dipole moment. The dipole moment makes possible the phenomena of lightning.

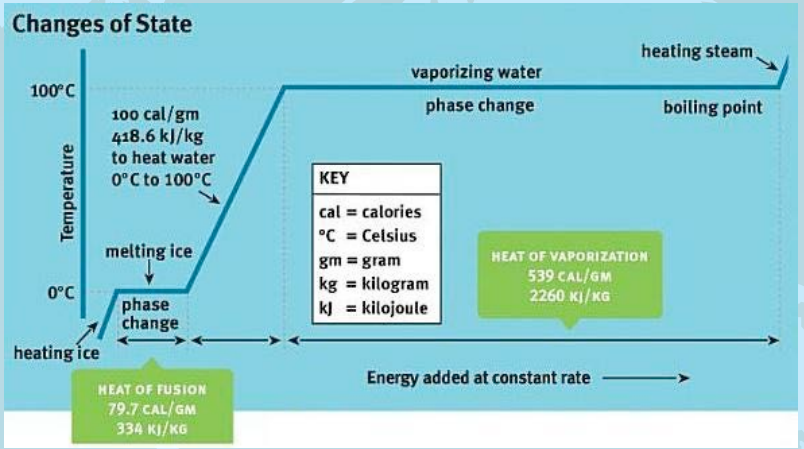
Energy Associated with Changes of State



Energy Associated with Changes of State



Energy Associated with Changes of State



Latent Heat of Sublimation

Water molecules move directly from the ice surface to water vapor in the air.

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˚C.

Add 540 calories to evaporate the liquid.

Total Energy ADDED for sublimation of 1 gram of ice: 80 + 100 + 540 = 720 calories

Latent Heat of Deposition

Vapor (water molecules) in the air move directly to the surface of an ice crystal.

Take one gram of water vapor at 100 degrees C.

Release 540 calories to condense.

Release 100 calories to cool temperature of liquid to 0˚C.

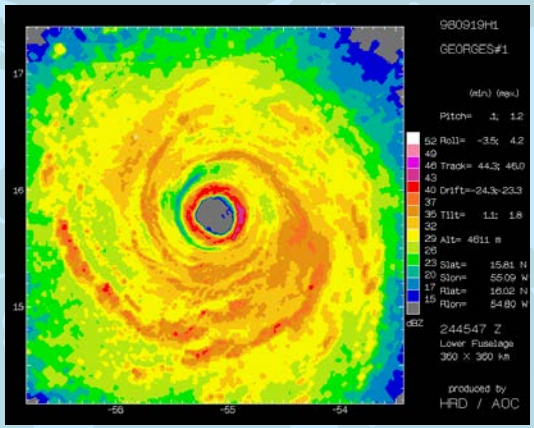
Release 80 calories to freeze water.

Total energy RELEASED for deposition of 1 gram of ice: 540 + 100 + 80 = 720 calories

Latent Heat and Storms

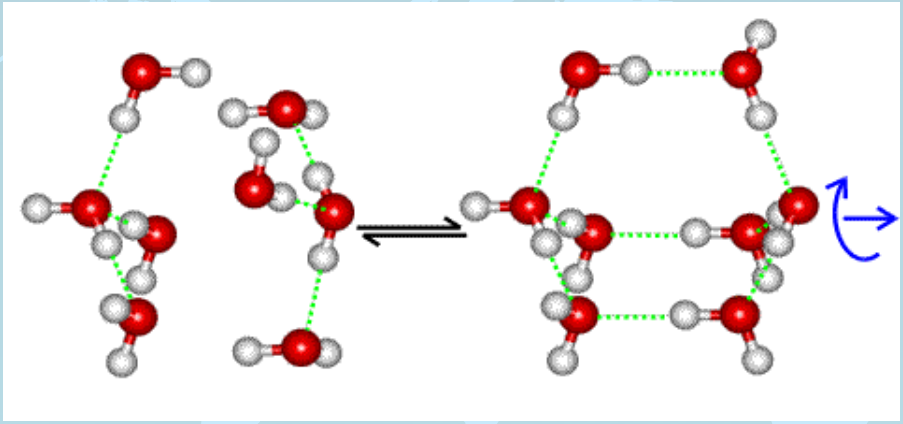
The large latent heats associated with changes of state and the low molecular weight of water make moist air potent fuel for thunderstorms and hurricanes.

Latent Heat and Storms



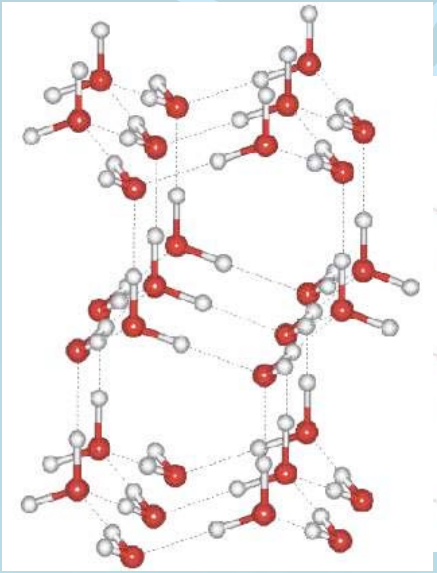
The large latent heats associated with changes of state and the low molecular weight of water make moist air potent fuel for thunderstorms and hurricanes.

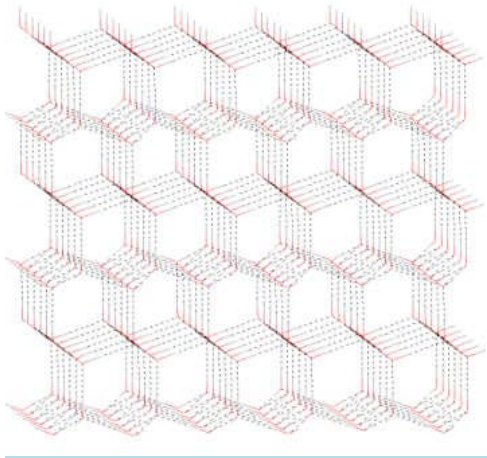
Crystal Structure of Ice



When water freezes the water molecules take up more space causing ice to float.

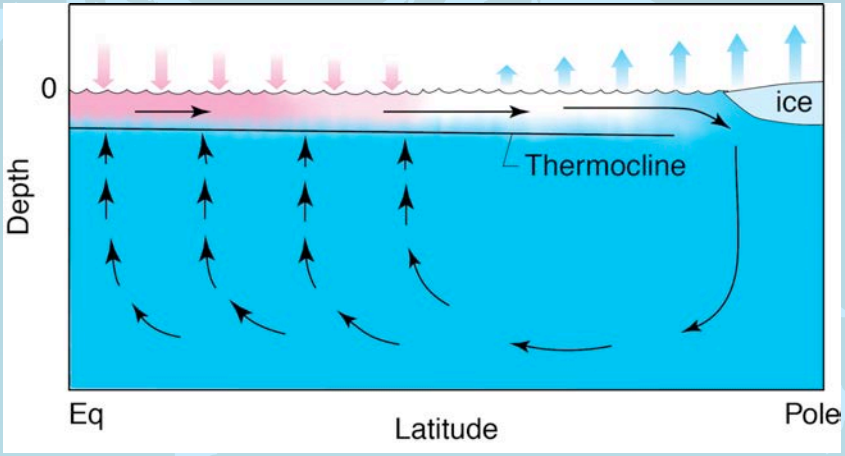
Crystal Structure of Ice





Crystal Structure of Ice

Water Density and Ocean Circulation



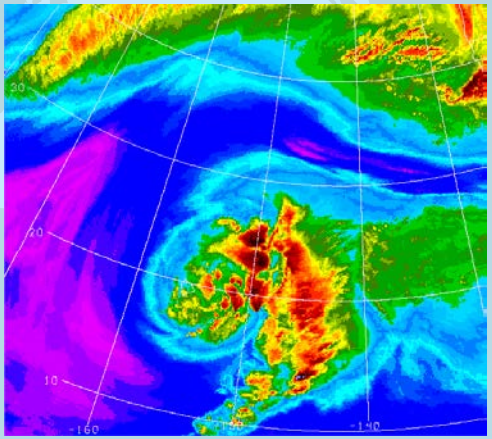
Liquid water has maximum density at +4˚C; solid phase has lower density.

Ice floats on water!

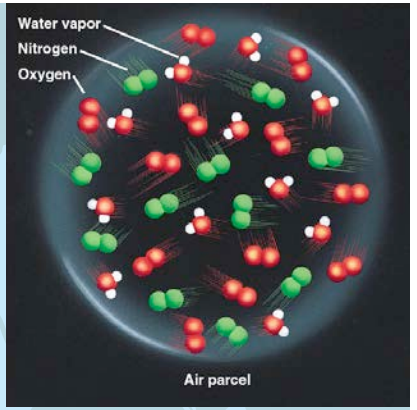
Water in the Atmosphere

Outline

- How do we measure water vapor in the atmosphere?
- The Hydrological Cycle



Water vapor pressure



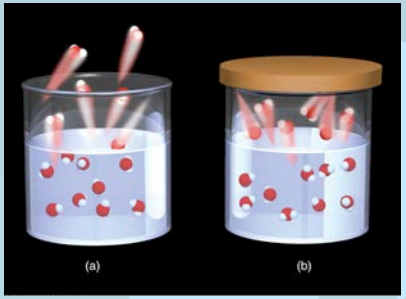
All the molecules in an air parcel contribute to pressure

Each subset of molecules (e.g., N_2, O_2, H_2O) exerts a partial pressure that depends on the number of molecules.

The vapor pressure of water is the pressure exerted only by water vapor molecules in the air

– often expressed in millibars (2-30 mb common at surface)

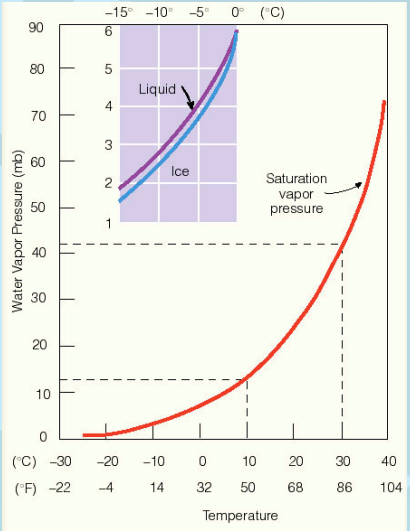
Water Vapor Saturation



- 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

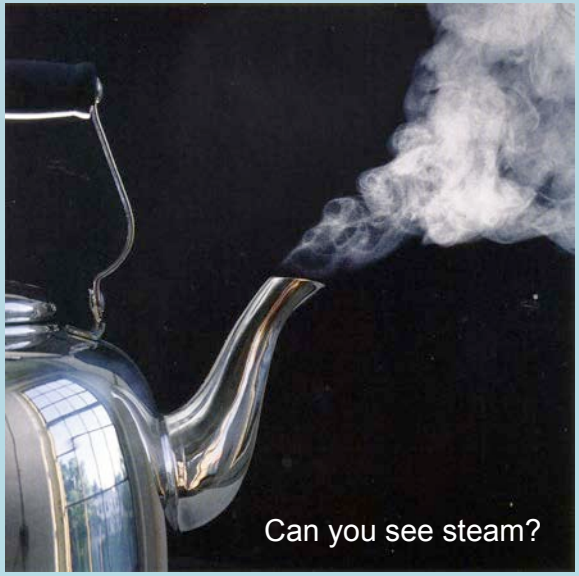
Saturation Vapor Pressure vs Temp.

- 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



Boiling Point

When the temperature of water is such that the vapor pressure equals the atmospheric pressure water will boil.



Expressing the Air's Water Vapor Content

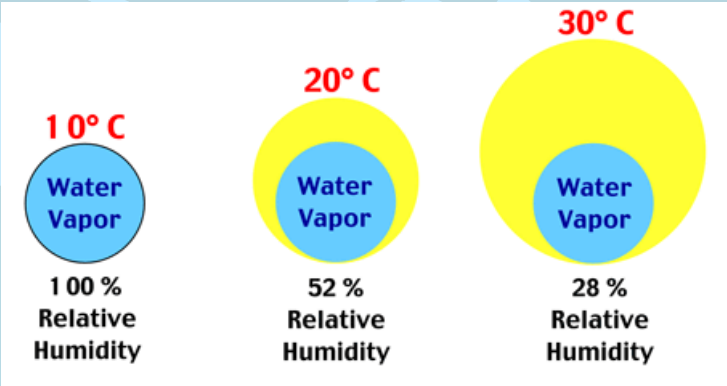
Relative Humidity (RH) is ratio of actual vapor pressure e to saturation vapor pressure e_s

- $100 * e/e_s$
- Range: 0-100% (+)
- Air with RH > 100% is supersaturated

RH can be changed by

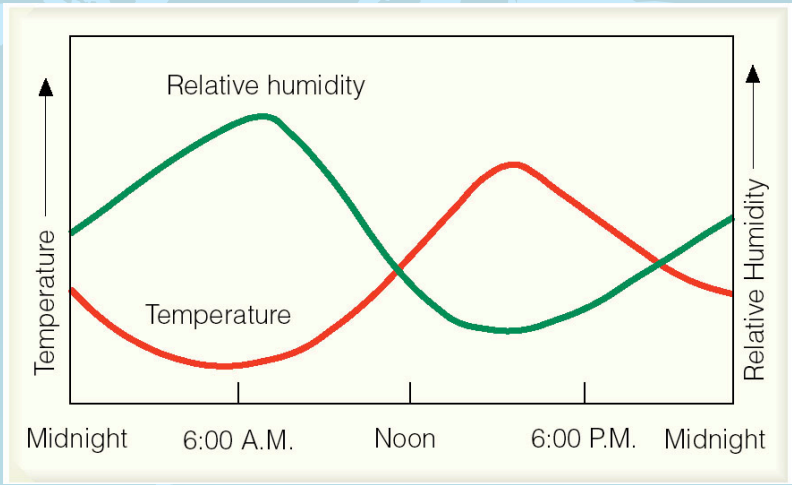
- Changes in water vapor content.
- Changes in temperature, which alter the saturation vapor pressure.

Temperature Changes and Relative Humidity



The saturation vapor pressure of water increases with temperature. Therefore, if the amount of water in the air stays the same, but the temperature increases, then the relative humidity drops.

Diurnal Temperature Changes and Relative Humidity



What time is best to water plants to minimize evaporation?

Expressing the Air's Water Vapor Content

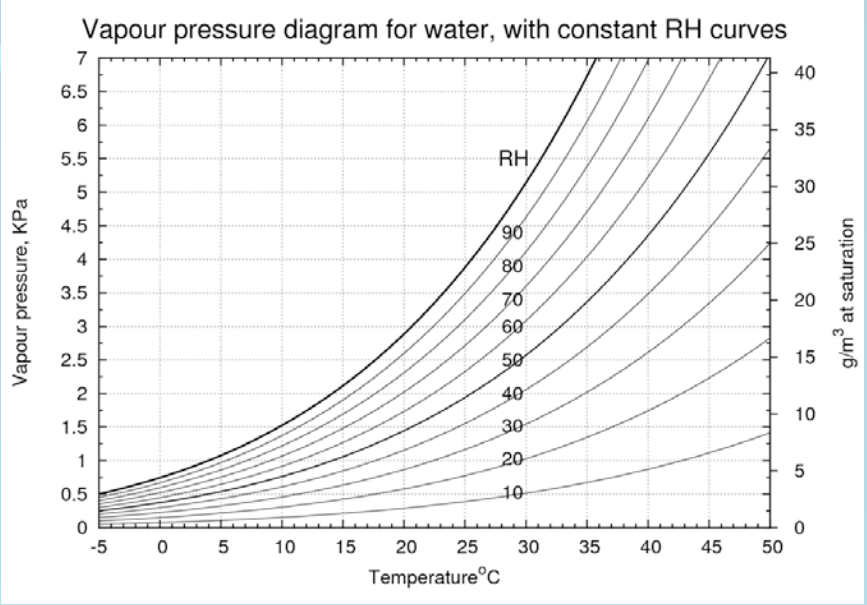
Mixing ratio – mass of water vapor/mass of dry air (g/kg)

Specific Humidity - is the ratio of the mass of water vapor to the mass of dry air plus water vapor, and is sometimes referred to as humidity ratio.

Dew point temperature – temperature to which an air parcel must be cooled for condensation to take place.

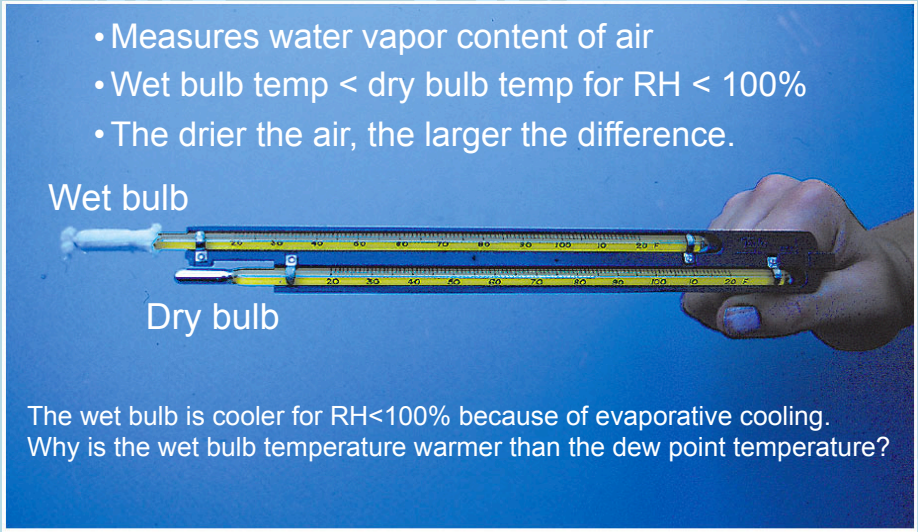
Wet bulb temperature – temperature to which evaporation will cool a wet thermometer.

Saturation Vapor Pressure & Mixing Ratio vs Temp.



The Sling Psychrometer

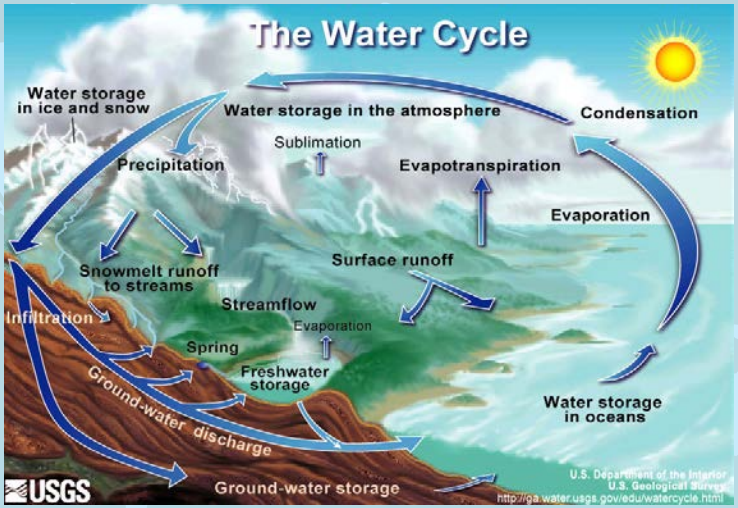
- Measures water vapor content of air
- Wet bulb temp < dry bulb temp for RH < 100%
- The drier the air, the larger the difference.



The wet bulb is cooler for RH<100% because of evaporative cooling.
Why is the wet bulb temperature warmer than the dew point temperature?

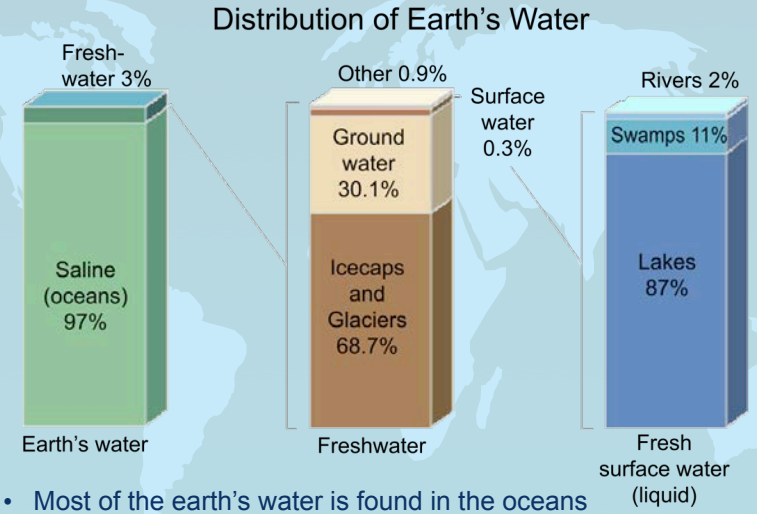
The Hydrological Cycle

The Earth's Hydrologic Cycle



Ocean covers 71% of the Earth's surface. On average globally, 1 meter of water is evaporated and falls as precipitation each year.

Earth's Water Distribution



- Most of the earth's water is found in the oceans
- only 3% is fresh water and >2/3 of that is ice
- The atmosphere contains only ~ 1 week supply of precipitation

Which environment has higher water vapor content?

Polar Air
- Air temperature -2˚C
- Dew point -2˚C
- Relative humidity 100%

Desert Air
- Air temperature 35˚C
- Dew point 5˚C
- Relative humidity 16%

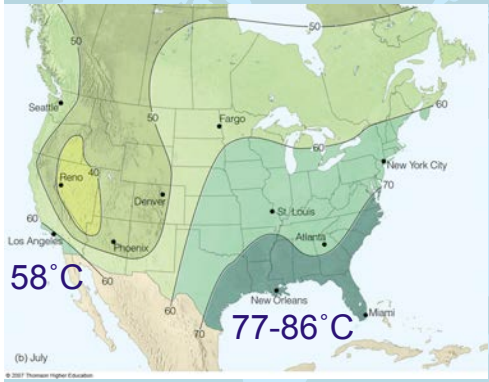
Why is the southwest coast of the US dry while the Gulf coast is humid?

- 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?

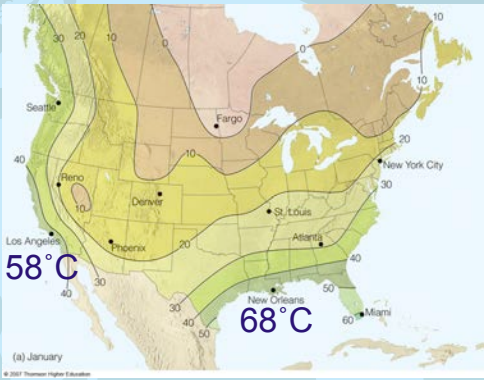
Why is the southwest coast of the US hot and dry while the Gulf coast is hot and humid?

Average surface dew-point temperature (˚F)

summer

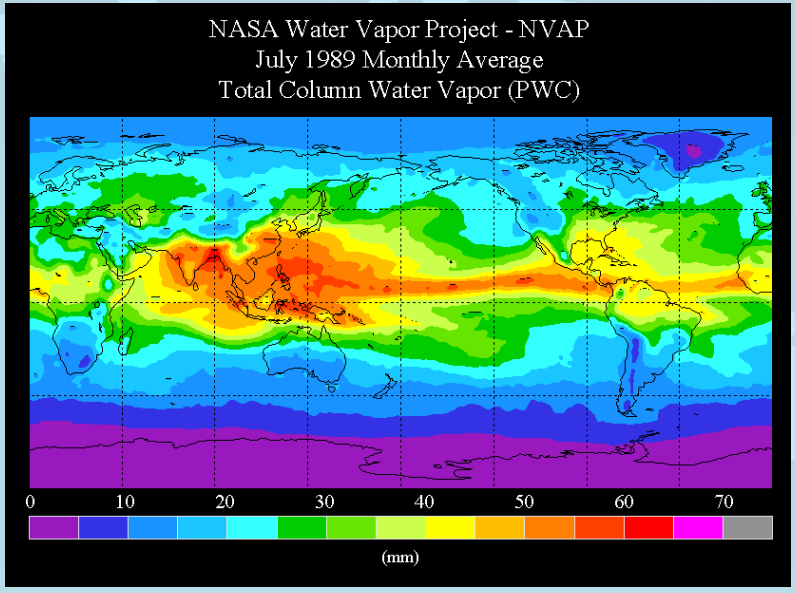


winter



The cold ocean temperatures typically found off the west coast of continents are a result of oceanic upwelling. Dew point temperatures are driven by the sea surface temperatures.

Where is the Water Vapor?

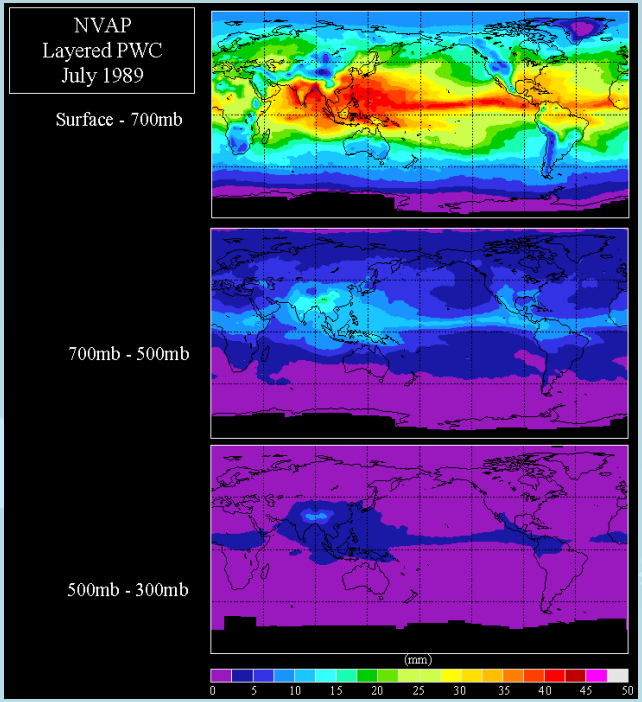


Water Vapor Decreases with Elevation

The largest amounts of water vapor are found close to the surface, with decreasing amount at higher elevations

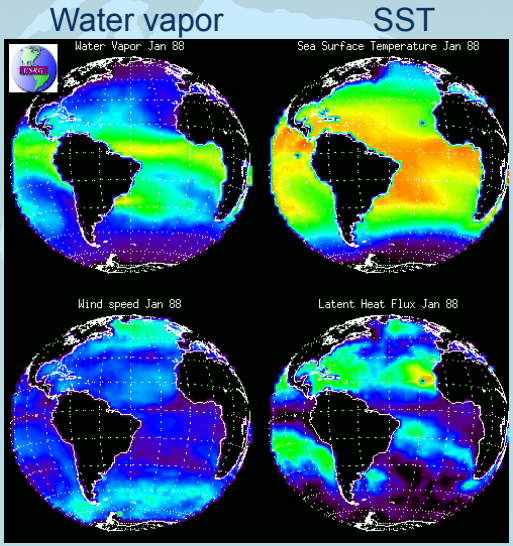
- Closest to the source - evaporation from ground, plants, lakes and ocean
- Warmer air can hold more water vapor than colder air

Water Vapor Decreases with Elevation

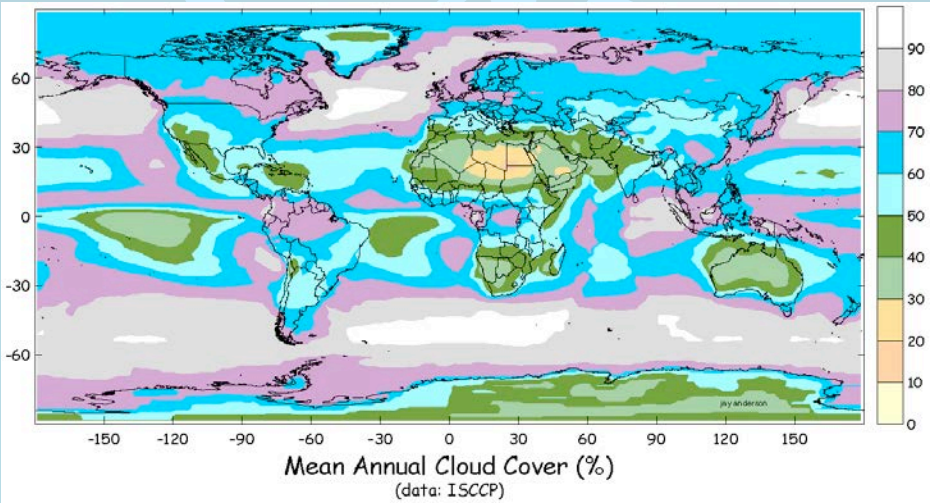


Sources of Atmospheric Water

- Water vapor is concentrated in the tropics.
- Evaporation from the sea surface depends on temp, wind, and RH.
- The greatest source of water vapor is in the subtropics.



Mean Annual Cloud Cover



Questions?