Key words

Radiation imbalance (heat transport by atmosphere and ocean currents)
Radiational cooling, radiation inversion, thermal belt
Specific heat, controls of temperature
Diurnal range of temperature
Wind-chill index
Radiometer

Lecture 7
Water in the Atmosphere
Properties of Water

• Physical States
  – only natural substance that occurs naturally in three states on the earth’s surface

• Specific Heat
  – Highest of all common solids and liquids

• Latent Heat of Fusion
  – Highest of all common substances

Properties of Water

• 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 Changes of State

- Heat energy taken from environment
- Sublimation
- Melting
- Freezing
- Liquid
- Evaporation
- Condensation
- Deposition
- Heat energy released to environment

Water Vapor Saturation

- Water molecules move between 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
Why does it take so much energy to evaporate water?

**Hydrogen bond.** In the liquid state, adjacent water molecules attract one another: “-” charge on O attracted to “+” charge on H

- The attraction created by hydrogen bonds keeps water liquid over a wider range of temperature than is found for any other molecule its size.
- A large amount of energy is needed to convert liquid water, where the molecules are attracted through their hydrogen bonds, to water vapor, where they are not.

Why does it take so much energy to evaporate water?

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.
Latent Heat and Storms

Water vapor pressure

• All the molecules in an air parcel contribute to pressure
• Each subset of molecules (e.g., N₂, O₂, H₂O) 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)
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

Expressing Water Vapor Content I

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

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

The Sling Psychrometer

Measures water vapor content of air

- Dry bulk temp > web bulb temp for RH < 100%
- The drier the environ, the larger the difference.
Find dew point temperature

\[ \times \ 20^\circ C \]

\[ \times \ 10^\circ C \]

Temperature drops upward at 6.5 \( ^\circ C/km \)

\[ \rightarrow \text{Humidity decreases rapidly with height.} \]

Which environment has higher water vapor content?

(a) POLAR AIR: Air temperature \(-2^\circ C (28^\circ F)\)
   Dew point \(-2^\circ C (28^\circ F)\)
   Relative humidity 100 percent

(b) DESERT AIR: Air temperature \(35^\circ C (95^\circ F)\)
   Dew point \(5^\circ C (41^\circ F)\)
   Relative humidity 16 percent
Relative humidity (that affects evaporation rate) and human discomfort (summer)

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On global average, 1 m water per m² is evaporated and fall as precipitation.
Earth’s Water Distribution

Condensation (RH > 100%) ➔ fog, cloud, precipitation
A decrease in temperature may cause condensation and cloud droplet formation, with the help of condensation nuclei (dust, smoke, salt …)

Dew ($T_d > 0^\circ C$)

Radiation cooling on ground at night

$T < T_d$

Frost ($T_d < 0^\circ C$)
Haze

- Small droplets that may form at RH < 100% (hygroscopic nuclei: salt, sulfuric and nitric acid).
- Becomes visible by scattering light.

Fog: droplets larger than haze and visibility < 1 km.

Radiation fog

- Forms at night due to longwave radiation cooling (often observed in valleys);
- Dissipates under sunlight as ground warms up by absorbing solar radiation.
Advection fog

Key words

Evaporation, condensation, precipitation
Saturated air, condensation nuclei, supersaturated air
Humidity, actual vapor pressure
Saturation vapor pressure, relative humidity, dew point
Dew, frost, fog
Radiation fog, advection fog, upslope fog,
evaporation/mixing fog