
Humidity, Condensation, and Clouds-I
GEOL 1350: Introduction To Meteorology

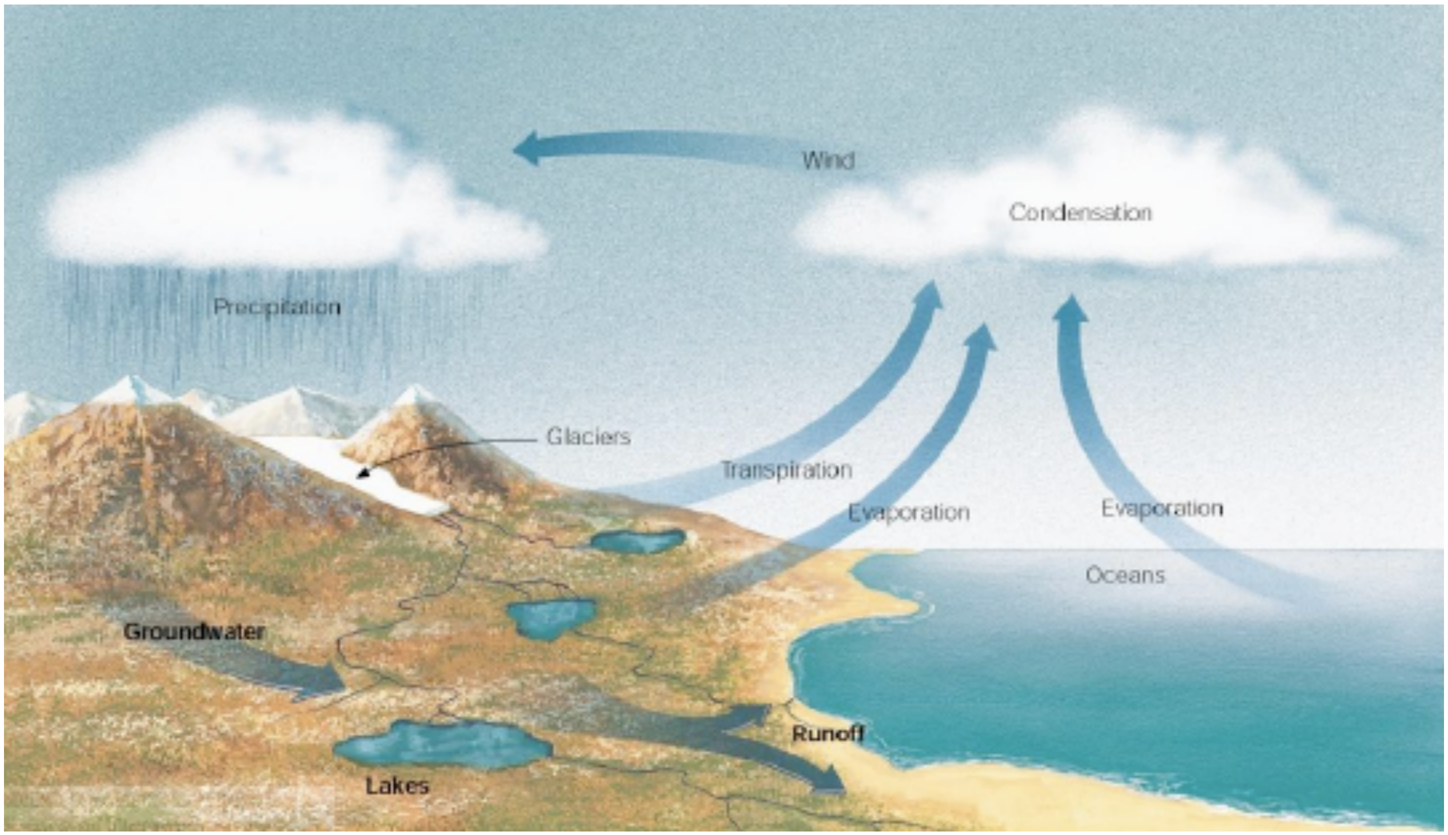
Overview

- Water Circulation in the Atmosphere

- Properties of Water

- Measures of Water Vapor in the Atmosphere (*Vapor Pressure, Absolute Humidity, Specific Humidity, Mixing Ratio, Relative Humidity, Dew Point*)

Where does the moisture in the atmosphere come from ?



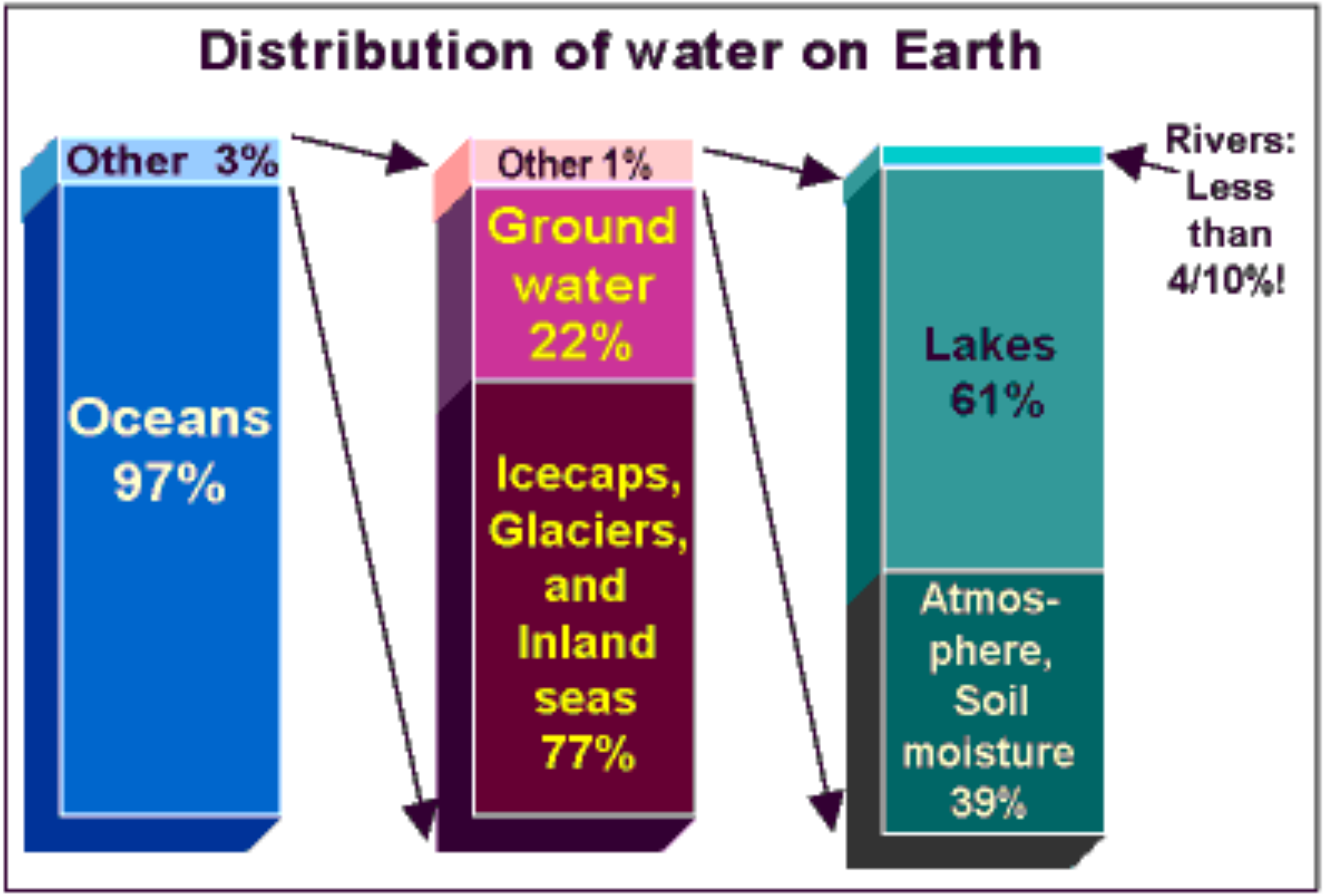
Major Source

Evaporation from ocean

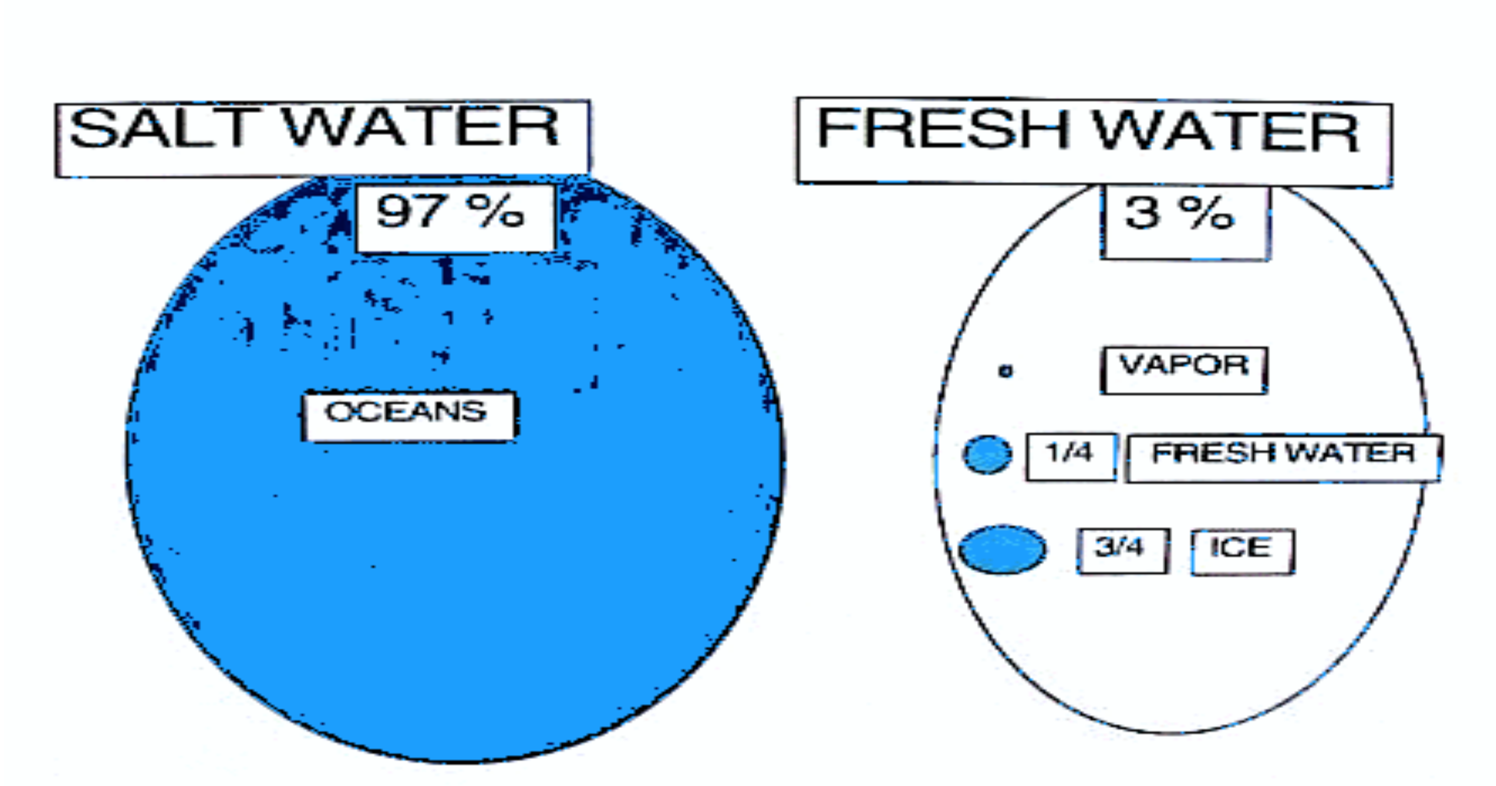
Major sink

Precipitation

Earth’s Water Distribution



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!**

Properties of Water

- **Physical States**

  only substance that are present naturally in three states

- **Density**

  liquid : ~ 1.0 g / cm^3 , solid: ~ 0.9 g / cm^3 , vapor: ~10^{-5} g / cm^3

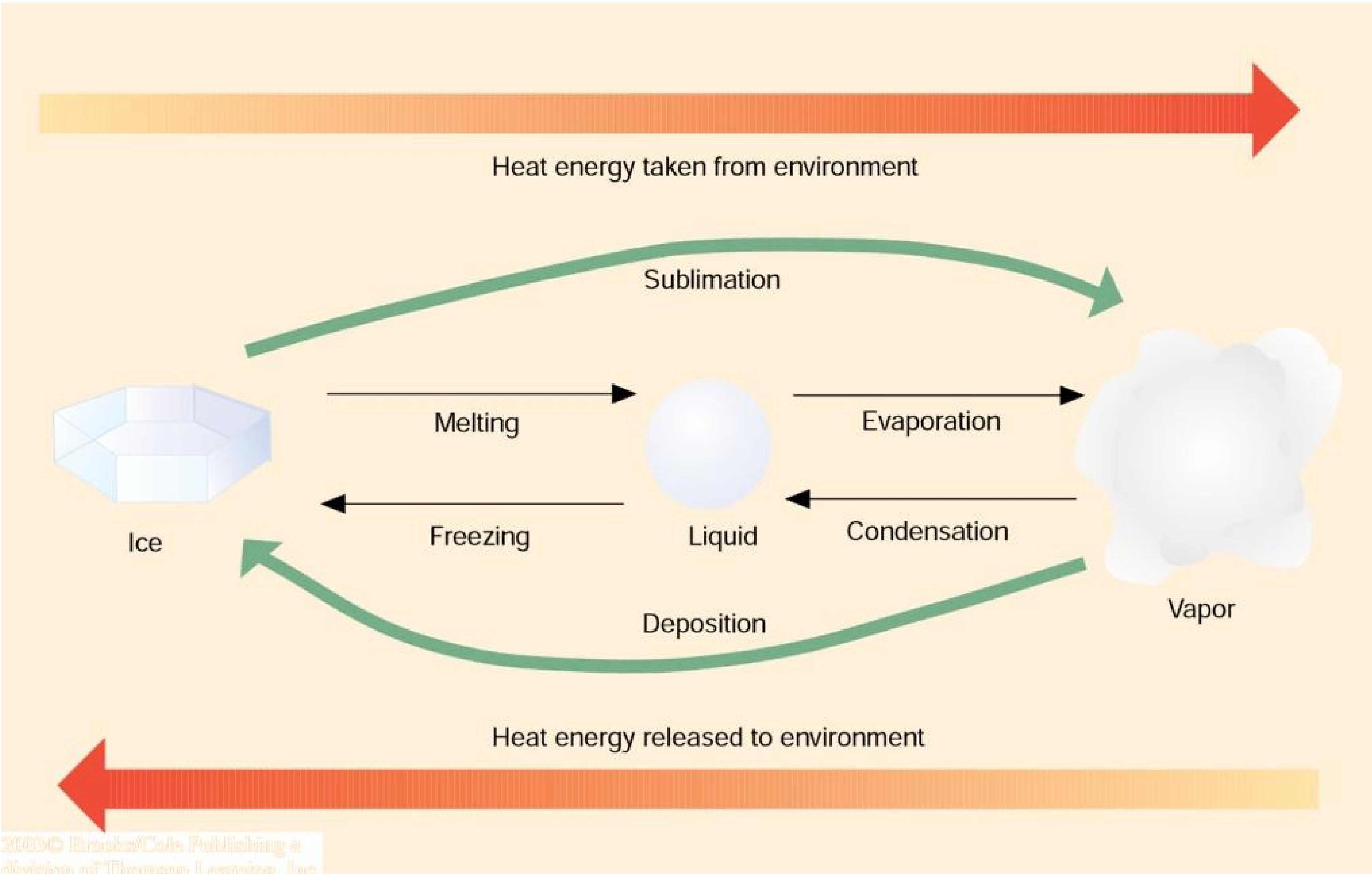
Properties of Water (cont')

- **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%**

Three phases of water

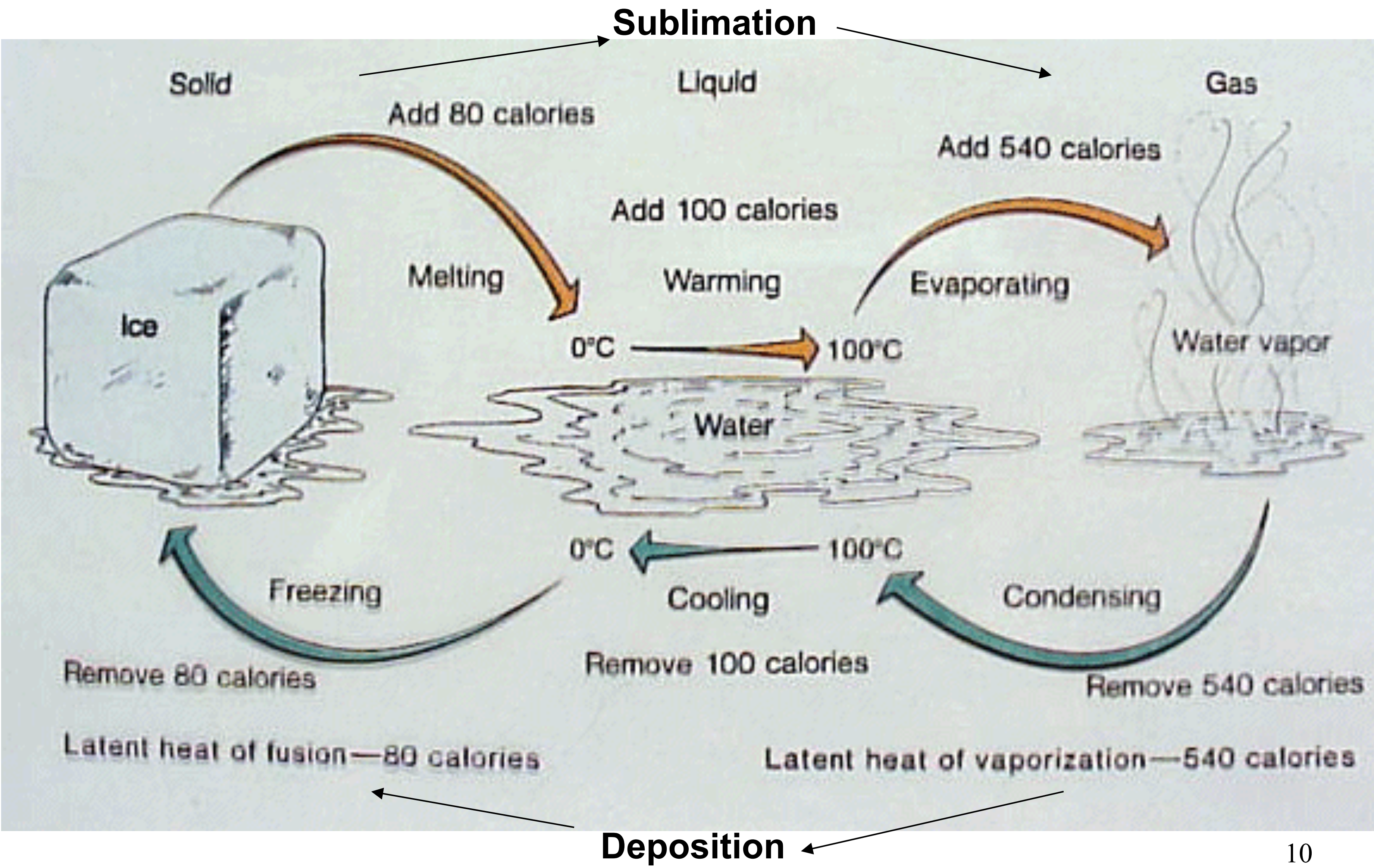
•Evaporation	liquid to vapor
•Condensation	vapor to liquid
•Sublimation	solid to vapor
•Deposition	vapor to solid
•Melting	solid to liquid
•Freezing	liquid to solid

Heat exchange with environment during phase change



As water moves toward vapor it absorbs latent heat to keep the molecules in rapid motion

Energy associated with phase change



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 **ADDED** for sublimation of 1 gram of ice:

80 + 100 + 540 = 720 calories

Remove **720 calories from its environment**

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 ^{o}C
Release 80 calories to freeze water

Total energy <u>RELEASED</u> for deposition of 1 gram of ice

540 + 100 + 80 = 720 calories

The environment *gain* 720 calories from deposition

Water Vapor

- M_v = 18 g/mole (H_2O)
- Most abundant trace gas
- Large variability: 0 – 4%
- Most important greenhouse gas
- Essential to weather and climate
- Source: evaporation from the ocean and land. Sink: precipitation.
- Large amount are found close the surface, decreasing aloft.

Measures of Water Vapor in the atmosphere

- **Vapor pressure** **e**
- **Absolute humidity** ρ_v
- **Specific humidity** **q**
- **Mixing ratio** **r**
- **Relative humidity** **RH**
- **Dew point temperature** T_d

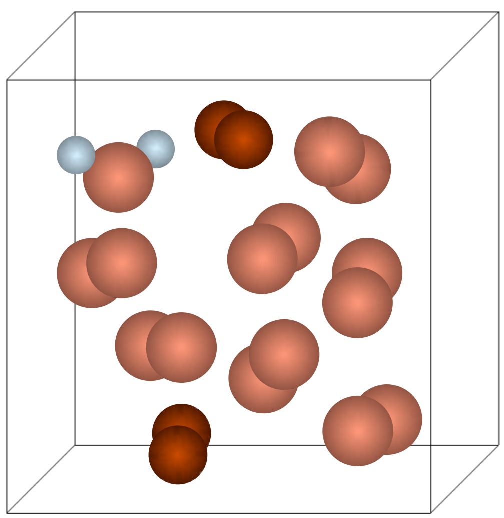
Vapor pressure - e

- Air molecules all contribute to pressure p
- Each subset of molecules (e.g., N_2, O_2, H_2O) 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
  - 2-30 mb common at surface
  - the larger the vapor pressure is, the more water vapor molecules in the atmosphere

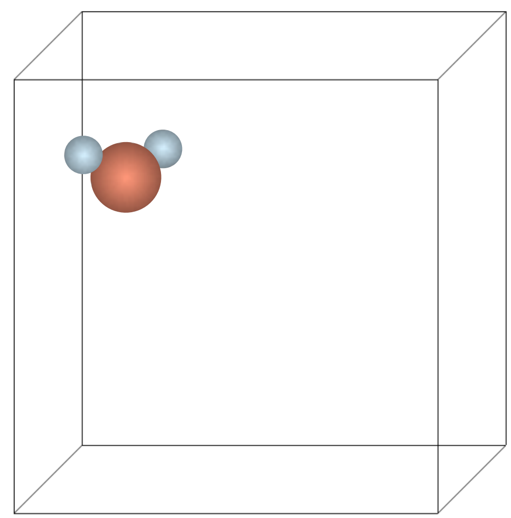
Vapor pressure - e

- Water vapor partial pressure

$e = p_{H2O}$

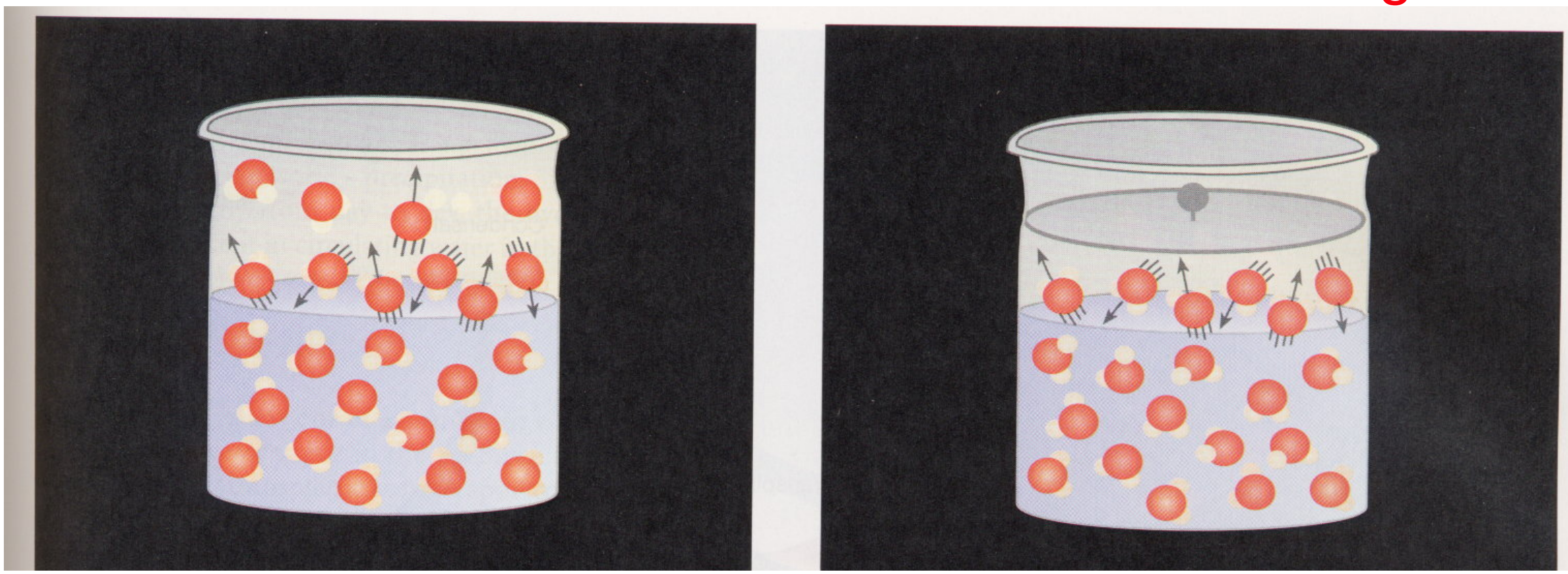


Total Pressure
$p = p_{O_2} + p_{N_2} + p_{H_2O}$



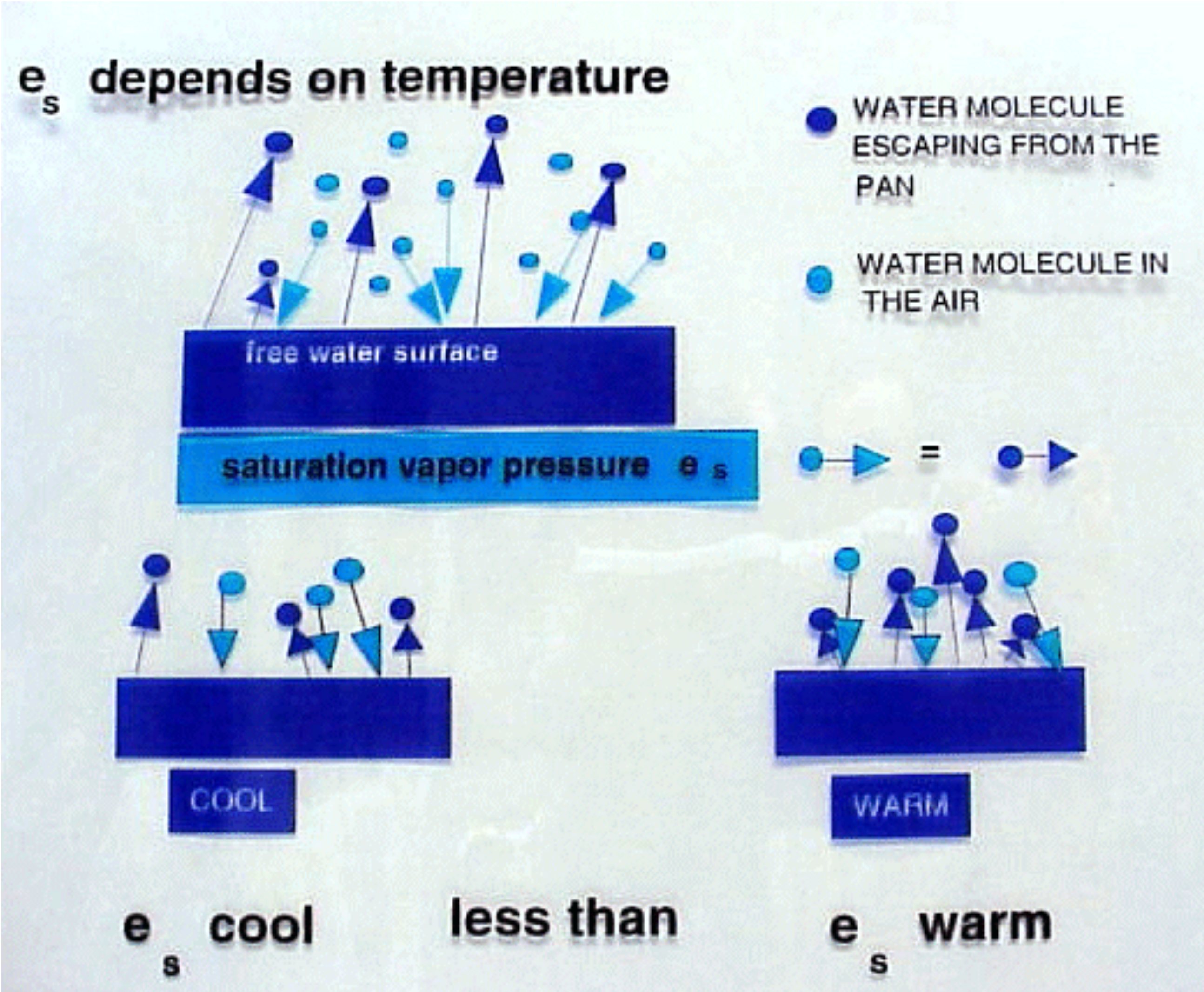
Water Vapor Pressure
$e = p_{H_2O}$

Saturation vapor pressure e_s



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

Saturation vapor pressure e_s depends upon temperature
higher temperature, higher e_s,
more water vapor that the air can hold



- 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 vapor"
- 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, $e_{s(water)} > e_{s(ice)}$ at all temperatures

At T=50 ^{o}F,

Es = 12 mb

At T=86 ^{o}F,

Es = 41 mb

At T= - 10 ^{o}C,

Es (water) = 2.8 mb

Es (ice) = 2.5 mb

Es water > Es ice

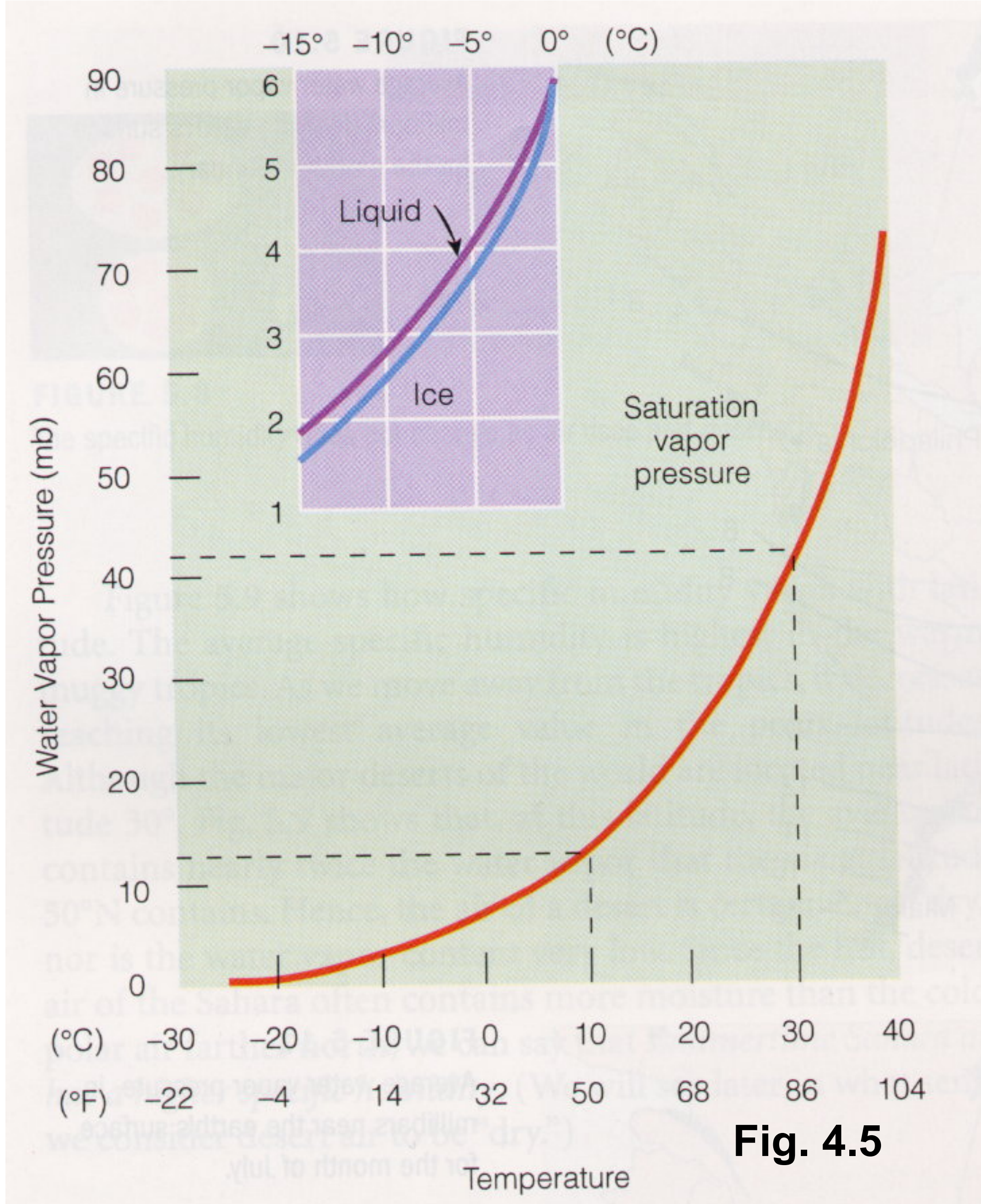


Fig. 4.5

Absolute Humidity - ρ_v

- **Density** of water vapor
  - A measure of the **total number** (mass) of **water vapor** molecules in **a unit volume** of air (1 m^3)

  - **Absolute humidity = mass of water vapor / volume of air**

    $\rho_v = m_v / V_{air}$, $m_v = n_v M_v$, M_v=18 g/mol

- **Changes in volume cause changes in absolute humidity**

Specific Humidity - q

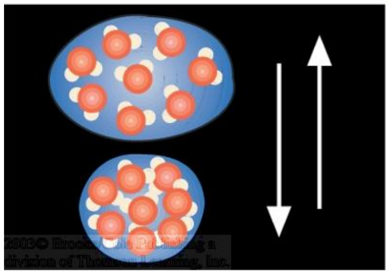
- Ratio of mass of water to <u>total</u> mass of air in a unit volume
- Invariant to change in volume

$$q = \frac{m_v}{m}$$

Since q is on the order of 10^{-3} g_v/g_a, we prefer to use g_v/kg_a

q values normally range from 1 to 20 g_v/kg_a and decreases with increasing height

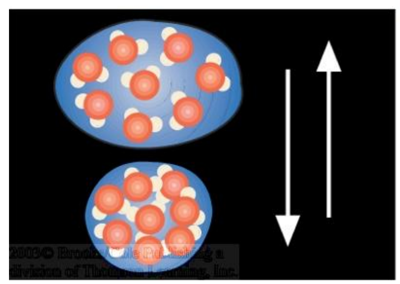
Absolute & Specific Humidity



Parcel Size	Mass of H_2O Vapor	Absolute Humidity
2 m^3	10 g	5 g/m^3
1 m^3	10 g	10 g/m^3

For a given mass of water vapor in an air parcel, the absolute humidity changes as the parcel volume changes (e.g., lifts or descends).

Specific humidity is concerned with the mass of vapor to mass of air, and is NOT affected by changes in parcel volume.



Mass of Parcel	Mass of H_2O Vapor	Specific Humidity
1 kg	1 g	1 g/kg
1 kg	1 g	1 g/kg

Mixing Ratio - r

- Ratio of mass of water to mass of dry air in a unit volume
- Invariant to change in volume

$$r = \frac{m_v}{m_d}$$

Usually, specific humidity ≈ mixing ratio

q ≈ r

Relative Humidity – R.H.

The ratio of the amount of water vapor in the air compared to the amount required for saturation.

R.H. = water vapor content / water vapor capacity

$$\mathrm{R.H.} = \frac{e}{e_s(T)} = \frac{\tilde{n}_v}{\tilde{n}_{vs}(T)} = \frac{q}{q_s(T)} = \frac{r}{r_s(T)}$$

Higher relative humidity does not necessarily mean more water vapor in the air

Changing the Relative Humidity

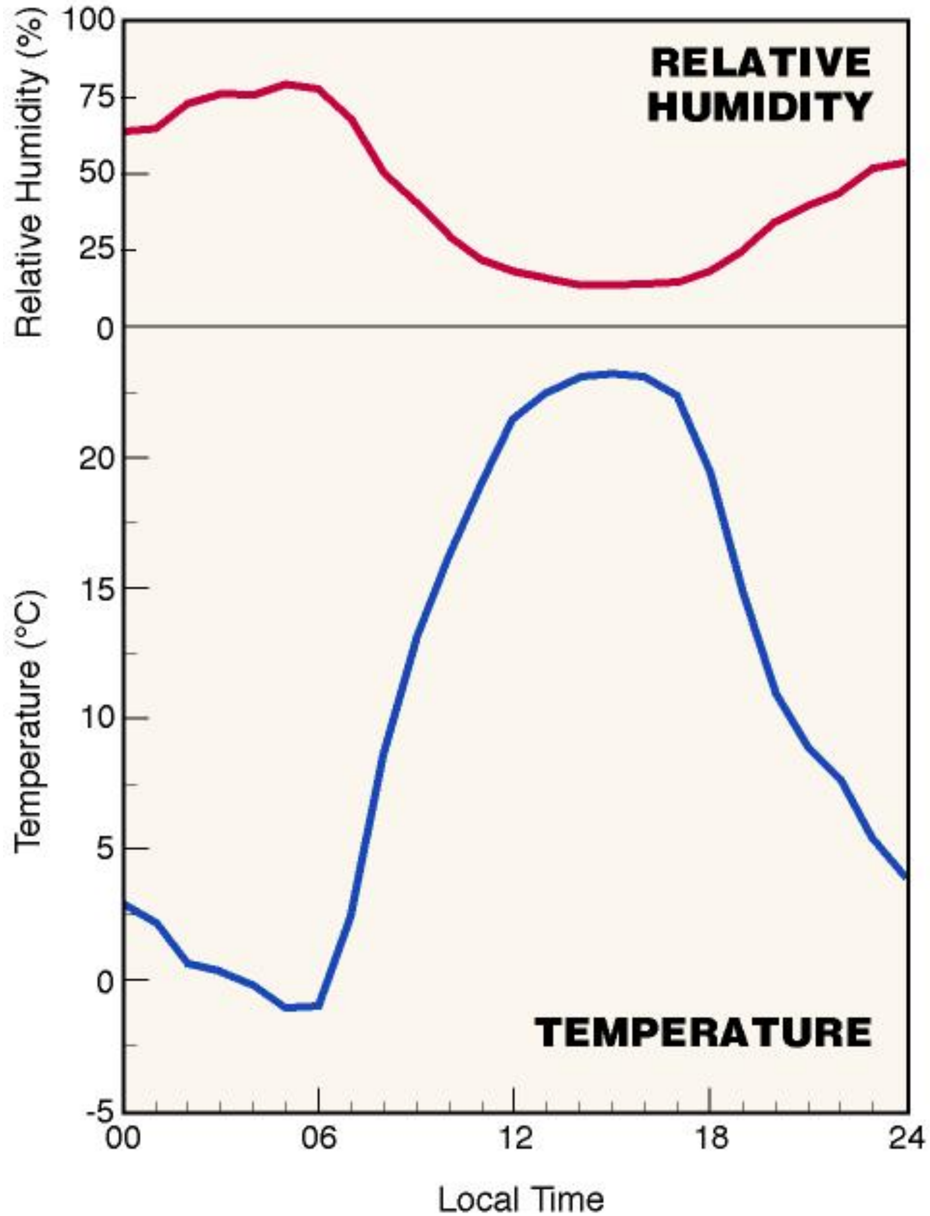
- Add/remove moisture
  - evaporation RH $\nearrow$
  - condensation RH $\searrow$

- Change temperature
  - cooling RH $\nearrow$
  - warming RH $\searrow$

Change of relative humidity in a day

What time of the day when relative humidity is usually high ?

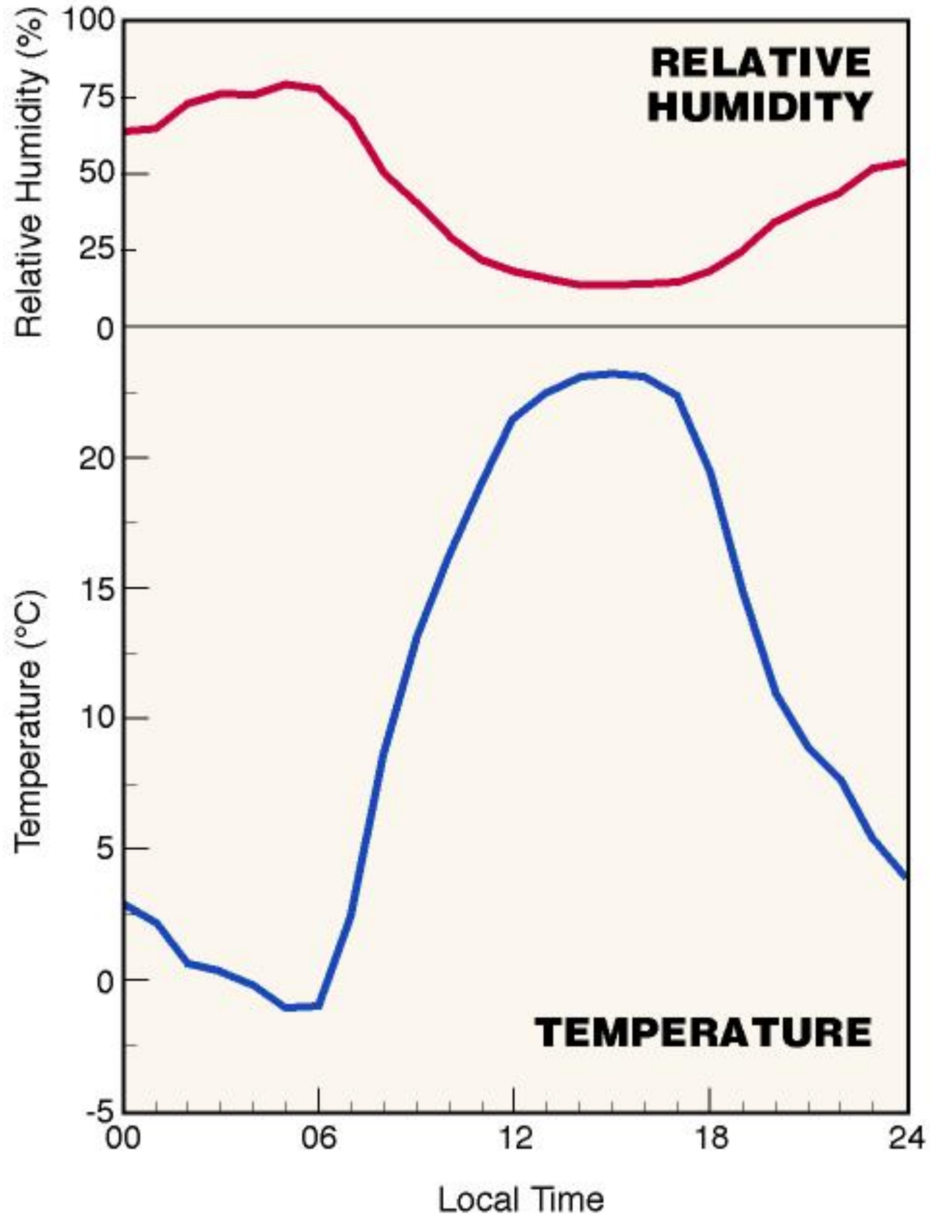
As the air cools during the night, the relative humidity increases. The highest relative humidity occurs in the early morning, during the coolest part of the day.



Change of relative humidity in a day

When it is usually low ?

As the air warms during the day, the relative humidity decreases, with the lowest values occurring during the warmest part of the afternoon.



Dew Point Temperature - T_d

- Temperature to which air must be cooled (at constant pressure and constant water vapor content) to become saturated.
- When $T=T_d$, $e_s(T_d) = e$, $q_s(T_d) = q$, $r_s(T_d) = r$
- $T_d \leq T$
- Unlike relative humidity which is a measure of how near the air is to being saturated, dew point temperature is a measure of its actual moisture content. *The higher the dew point, the more water vapor in the air.*

- Dew point depression: $T- T_d$
- The larger the dew point depression is, the drier the air is, or the air is farther away from saturation

Which environment has higher water vapor content? Desert air or polar air ?

POLAR AIR: Air temperature –2°C (28°F)
Dew point –2°C (28°F)
Relative humidity 100 percent

DESERT AIR: Air temperature 35°C (95°F)
Dew point 10°C (50°F)
Relative humidity 21 percent

Polar air has higher relative humidity. Desert air, with higher dew point, contains more water vapor.

Which environment has higher water vapor content? Desert air or polar air ?

POLAR AIR: Air temperature –2°C (28°F)
Dew point –2°C (28°F)
Relative humidity 100 percent

Because air temperature and dew point are the same in the polar air, the air is saturated and the relative humidity is 100%.

Which environment has higher water vapor content? Desert air or polar air ?

DESERT AIR: Air temperature 35°C (95°F)
Dew point 10°C (50°F)
Relative humidity 21 percent

Desert air, with a large separation between air temperature and dew point, has a lower relative humidity, 21%.

However, since dew point is a measure of the amount of water vapor in the air, the desert air must contain more water vapor.

Even polar air has a higher relative humidity, the desert air contains more water vapor.

A common misconception: air with high relative humidity must have a greater water vapor content than air with lower relative humidity.

Temperature (C)	Saturation mixing ratio (g/kg)
-20	0.75
-10	2
0	3.5
5	5
10	7
15	10
20	14

International fall

T = -10 C

q_s=2 g/kg,

RH=q/q_s=100%

q=1 x 2 =2 g/kg

Phoenix

T=20 C

q_s=14 g/kg,

RH=q/q_s=30%

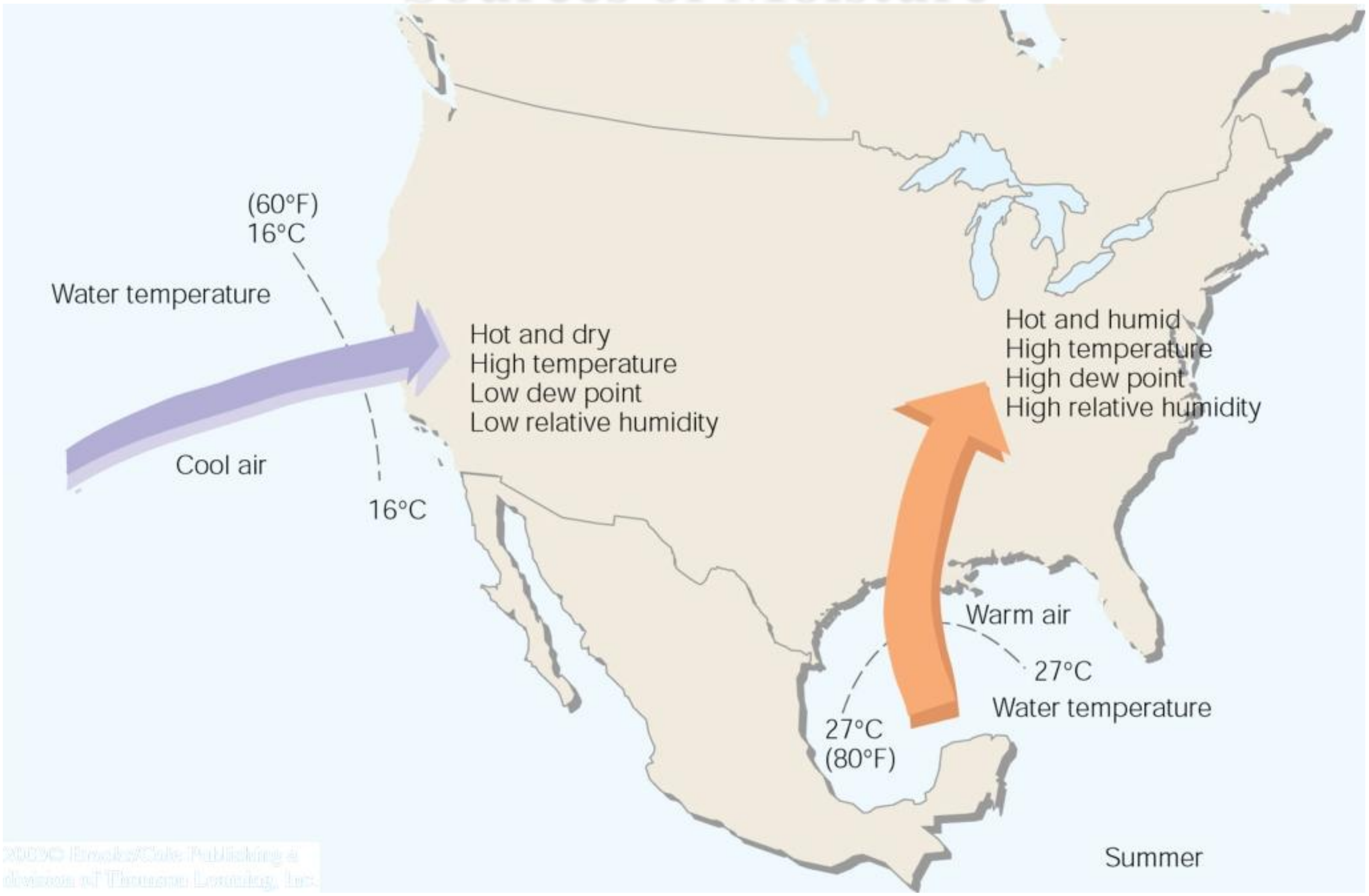
q=0.30 x 14

= 4.2 g/kg

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?**

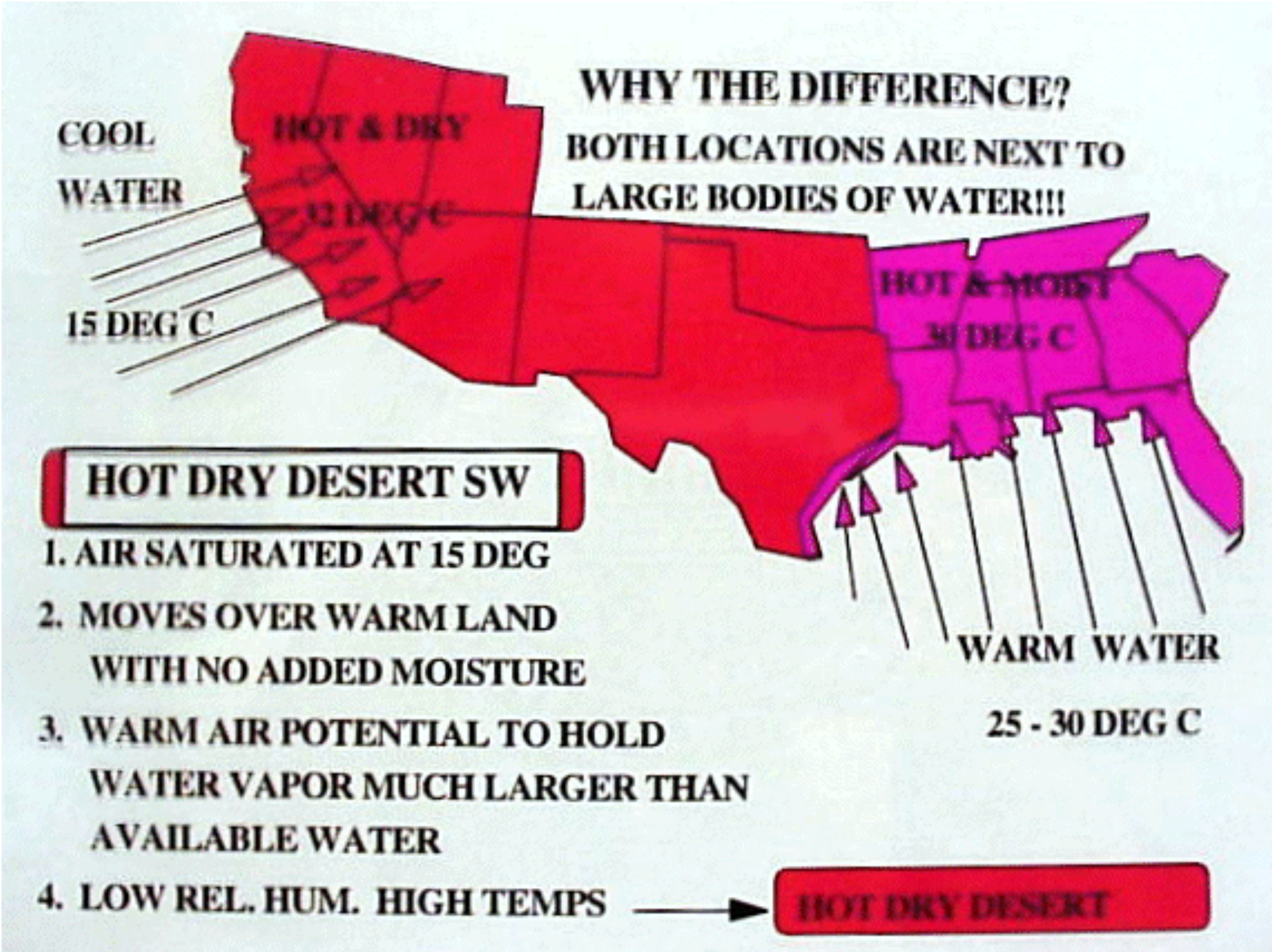
Sources of Moisture



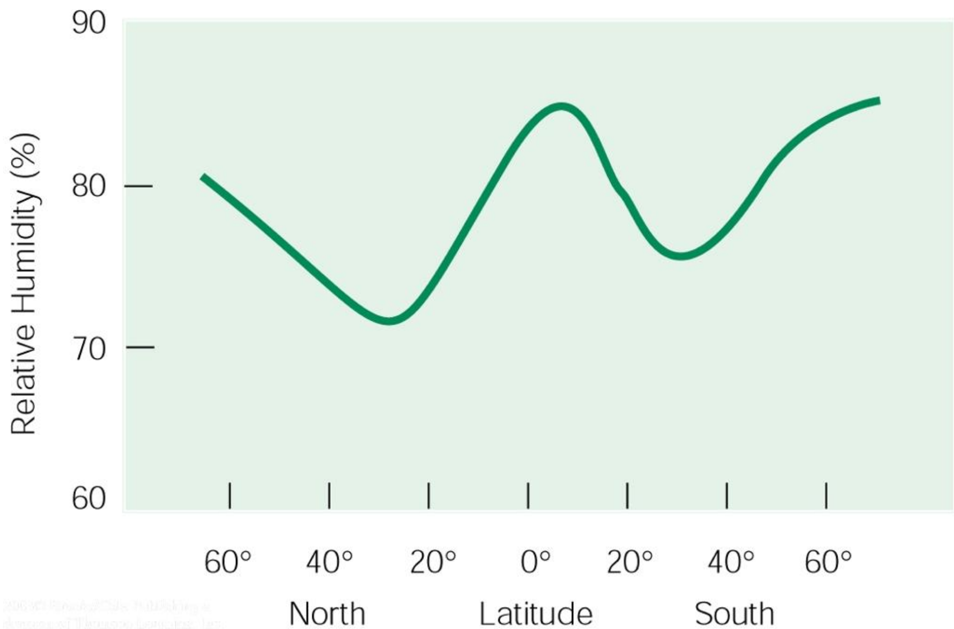
Patterns of US humidity are strongly governed by wind direction and ocean temperatures. Cooler Pacific waters create lower humidity in the west, while warmer Gulf waters generate high humidity along the southeast and east coast.

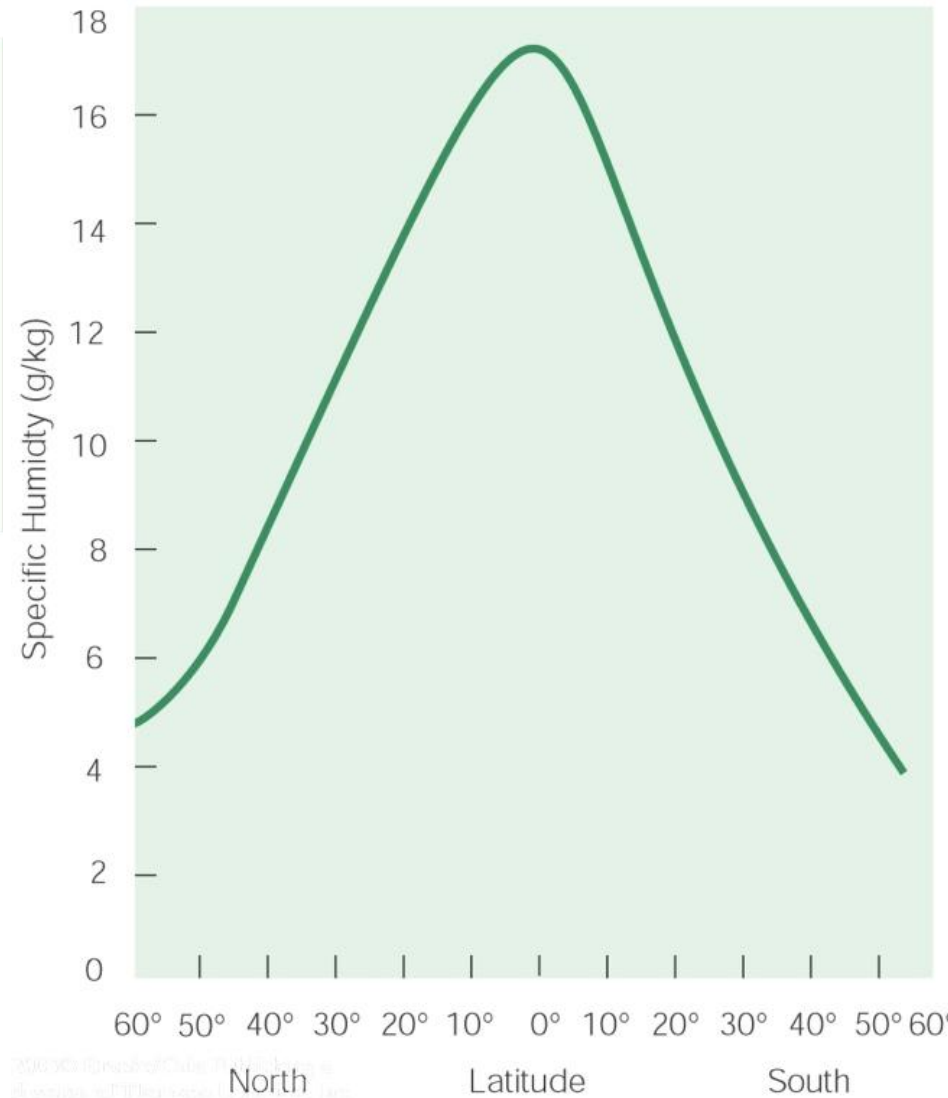
Humidity reflects water temps

The cold water temperatures typically found off the west coast of continents are a result of oceanic upwelling which ocean currents typically cause in these locations



Relative and Specific Humidity





Relative humidity (RH) as an indicator of saturation reveals that desert air is far from saturated, and that cold polar air nears saturation.

Graphs of RH contrast with specific humidity in the deserts and poles.

Early in the morning, temperature is 10 °C air is saturated R.H. = 100%

RH=e / e_s = 1

e_s(T=10C) = 12 mb

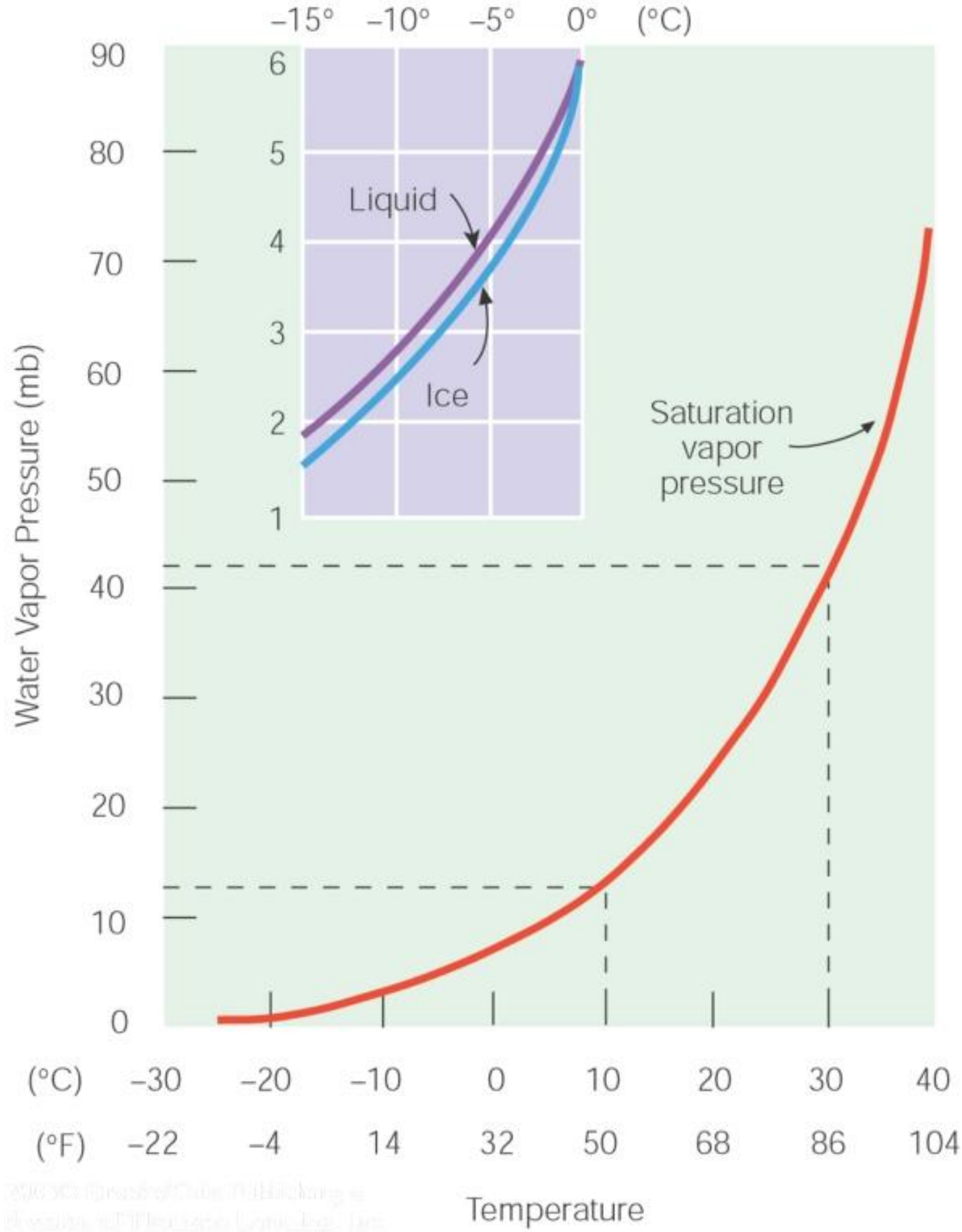
e = RH x e_s = 12 mb

In the afternoon, the air warms to 30 C

e_s(T=30C) = 42 mb

RH= e/e_s = 12 mb / 42 mb

= .29 = 29 %



Question:

If there is no change in moisture content, then to what temperature must the outside air be cooled in the evening so that it is once again saturated ?

10 ^oC - dew point temperature

Dew Point Temperature - T_d

- **Temperature to which air must be cooled (at constant pressure and constant water vapor content) to become saturated.**
- **When $T=T_d$, $e_s(T_d) = e$, $q_s(T_d) = q$, $r_s(T_d) = r$**
- **$T_d \le T$**
- **Unlike relative humidity which is a measure of how near the air is to being saturated, dew point temperature is a measure of its actual moisture content. *The higher the dew point, the more water vapor in the air.***

- **Dew point depression: $T - T_d$**
- **The larger the dew point depression is, the drier the air is, or the air is farther away from saturation**

If temperature T=15 C, the *saturation mixing ratio* at T=15 C is r_s =10 g/kg, which means that 1 kg of air can hold 10 g of water vapor at T=15 C before saturation

T (C)	r_s (g/kg)
-20	0.75
-10	2
0	3.5
5	5
10	7
15	10
20	14

If the actual mixing ratio is r = 7 g /kg < r_s=10 g/kg, which means that the air is unsaturated. Now, we cool the air and T drops. According the table when the temperature drops to 10 C, r_s = 7 g /kg, which is equal to the actual mixing ratio, and the air is now saturated. So T_d=10 C corresponding to r=7 g/kg. T-T_d=15-10=5 C

If the actual mixing ratio is r=5 g/kg, we have to cool the air to 5 C so that r_s= 5 g/kg = r and the air is saturated. So T_d = 5 C corresponding to r=5 g/kg

T-T_d=15-5=10 C

Higher dew point – more water vapor in the air

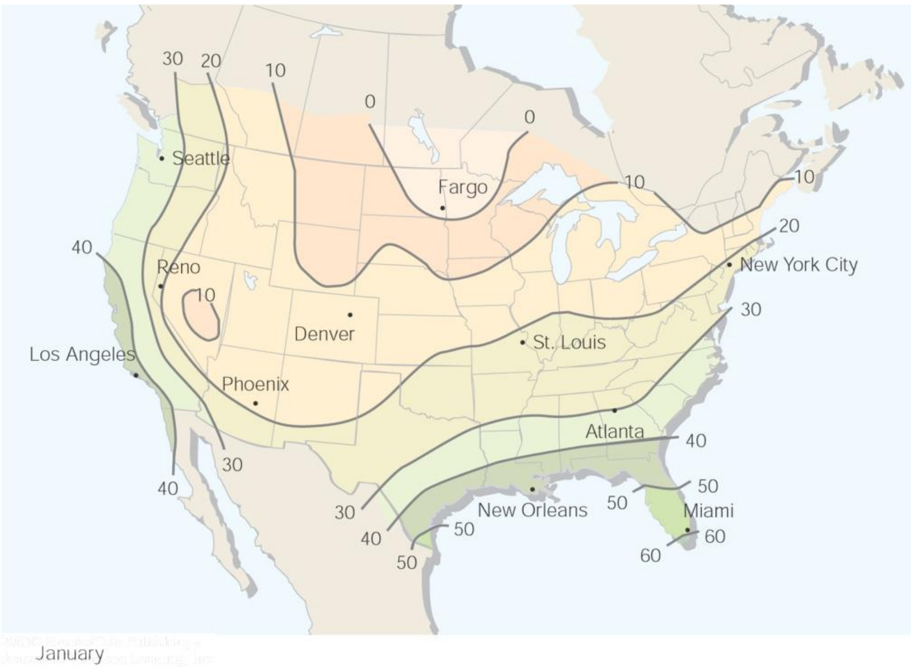
Smaller dew point depression, air is closer to saturation

T (C)	r_s (g/kg)
-20	0.75
-10	2
0	3.5
5	5
10	7
15	10
20	14

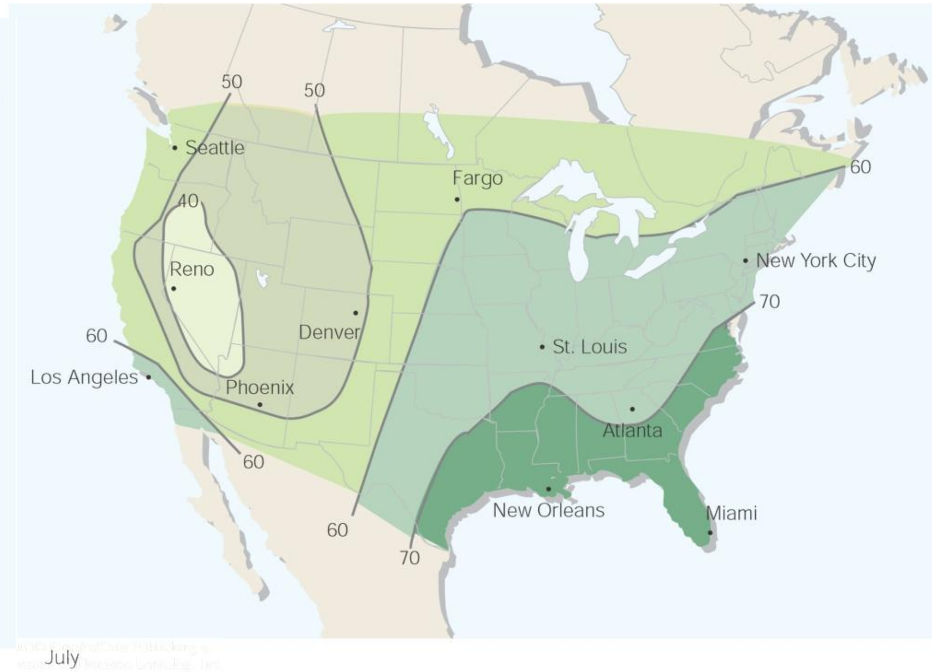
For every 10 °C (18°F) increase in dew point, the air contains about twice as much water vapor

Seasonal Dew Point Maps

Dew Point in Jan



Dew Point in Jul



Jan: Dew points are highest over Gulf Coast states and lowest over the interior.

Jul: Highest dew points are at Gulf Coast. Dew points at eastern and central USA are higher than in Jan. July air contains 3-6 times more water vapor than Jan.

How to Measure Dew Point Temperature ?

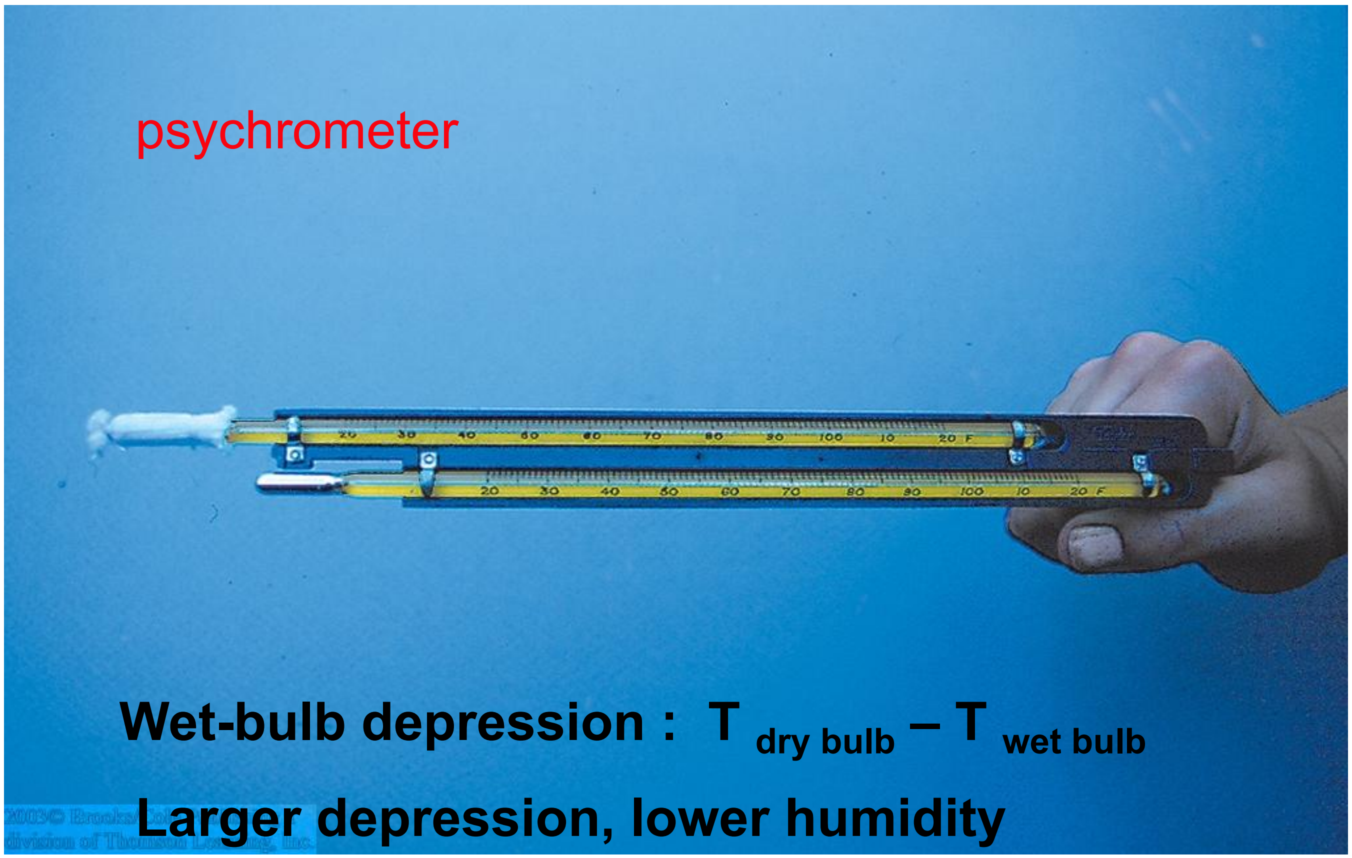
Dew-Point Hygrometer measures dew point temperature by cooling the surface of a mirror until condensation forms.

Reflecting a light beam off a chilled mirror. When the mirror temperature is cooled enough for dew to form on it, the light beam scatters off the dew drops instead of reflecting from the mirror. A photo detector records this change.

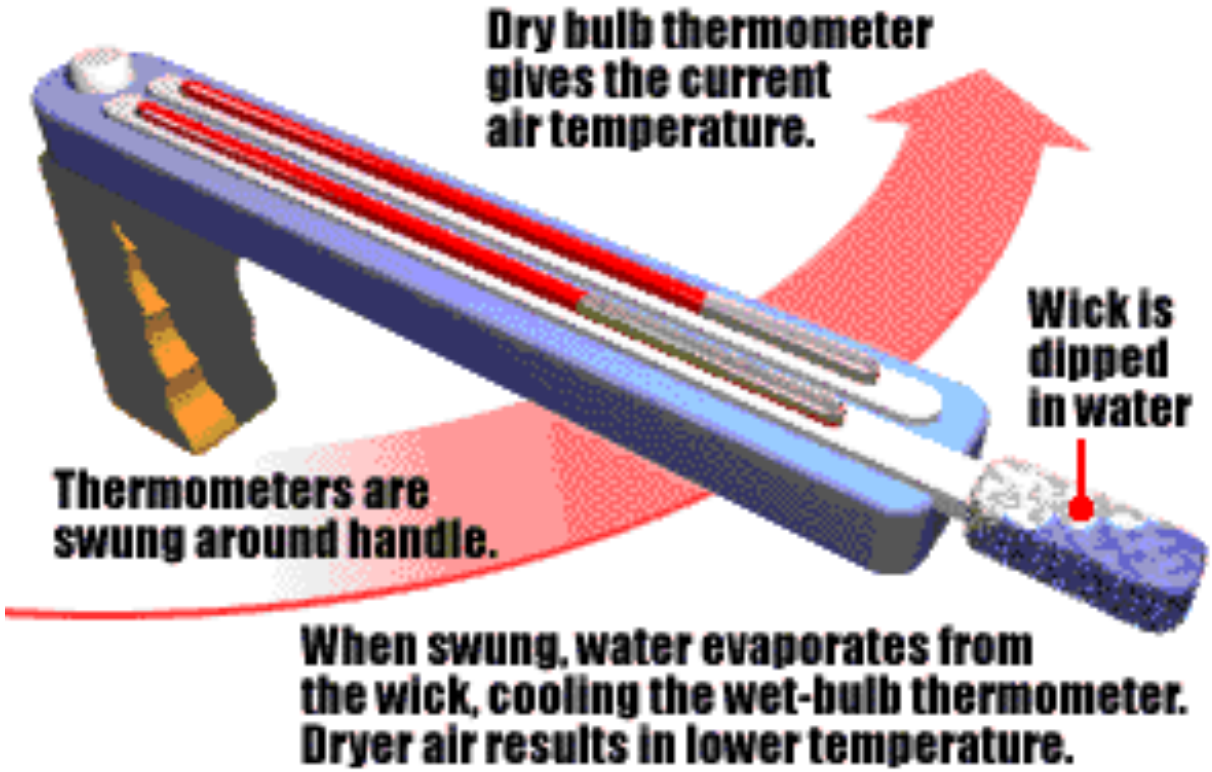
Used in the hundreds of fully automated weather stations - **A**utomated **S**urface **O**bserving **S**ystem (**ASOS**). Most accurate moisture measurements

Wet-bulb temperature - W_b

The lowest temperature that can be obtained by evaporating water into the air.



The Sling Psychrometer
Measures water vapor content of air



Why so many moisture variables ?

Useful conceptually

Vapor pressure

Absolute humidity

Useful in conservation equations

Specific humidity

Mixing ratio

Useful for describing how life is affected by humidity

Relative humidity

Useful because they can be measured

Dew point temperature (dew point depression)	Wet-bulb temperature (Wet-bulb depression)

Summary of moisture variables

Vapor pressure – the pressure exerted by the water vapor molecules in a given volume of air

Absolute humidity – the mass of water vapor in a given volume of air, or the density of water vapor

Specific humidity – the ratio of mass of water vapor in a given air parcel to the total mass of air in the parcel

Mixing ratio - the ratio of mass of water vapor in a given air parcel to the total mass of dry air in the parcel

Relative humidity – The ratio of the amount of water vapor in the air compared to the amount of required for saturation

Dew point temperature - Temperature to which air must be cooled (at constant pressure and constant water vapor content) to become saturated

Wet bulb temperature - The lowest temperature that can be obtained by evaporating water into the air.

SUMMARY

1. **Relative humidity does not tell us how much water vapor is actually in the air, rather it tells us how close the air is to being saturated.**

2. **Relative humidity can change when the air's water-vapor content changes, or when the air temperature changes.**

3. **With a constant amount of water vapor, cooling the air raises the relative humidity and warming the air lowers it.**

4. **The dew-point temperature is a good indicator of the air's water vapor content. High dew points indicate high water vapor content and vice versa.**

5. **Dry air can have a high relative humidity. In polar air, the dew-point temperature is low and the air is considered dry. But the air temperature is close to the dew point, and so the relative humidity is high.**