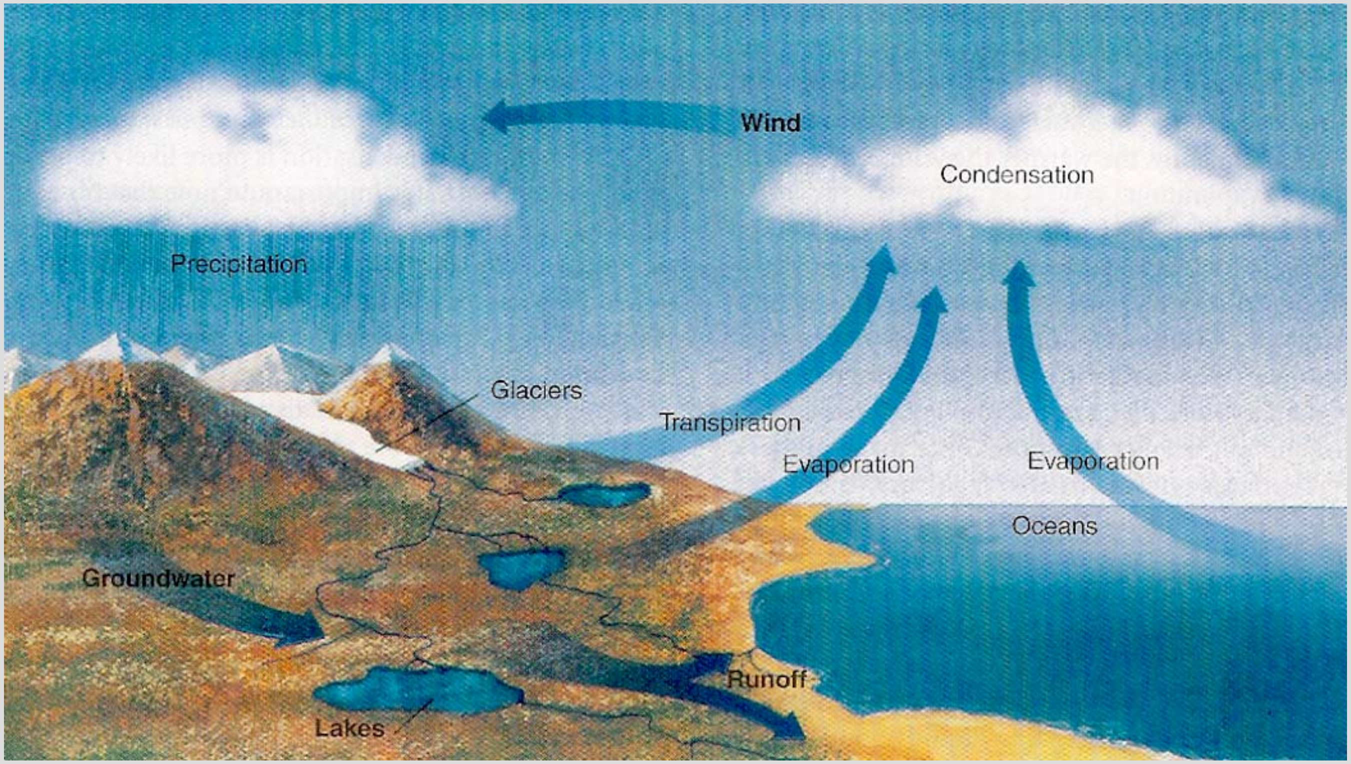
NATS 101
Section 13: Lecture 9

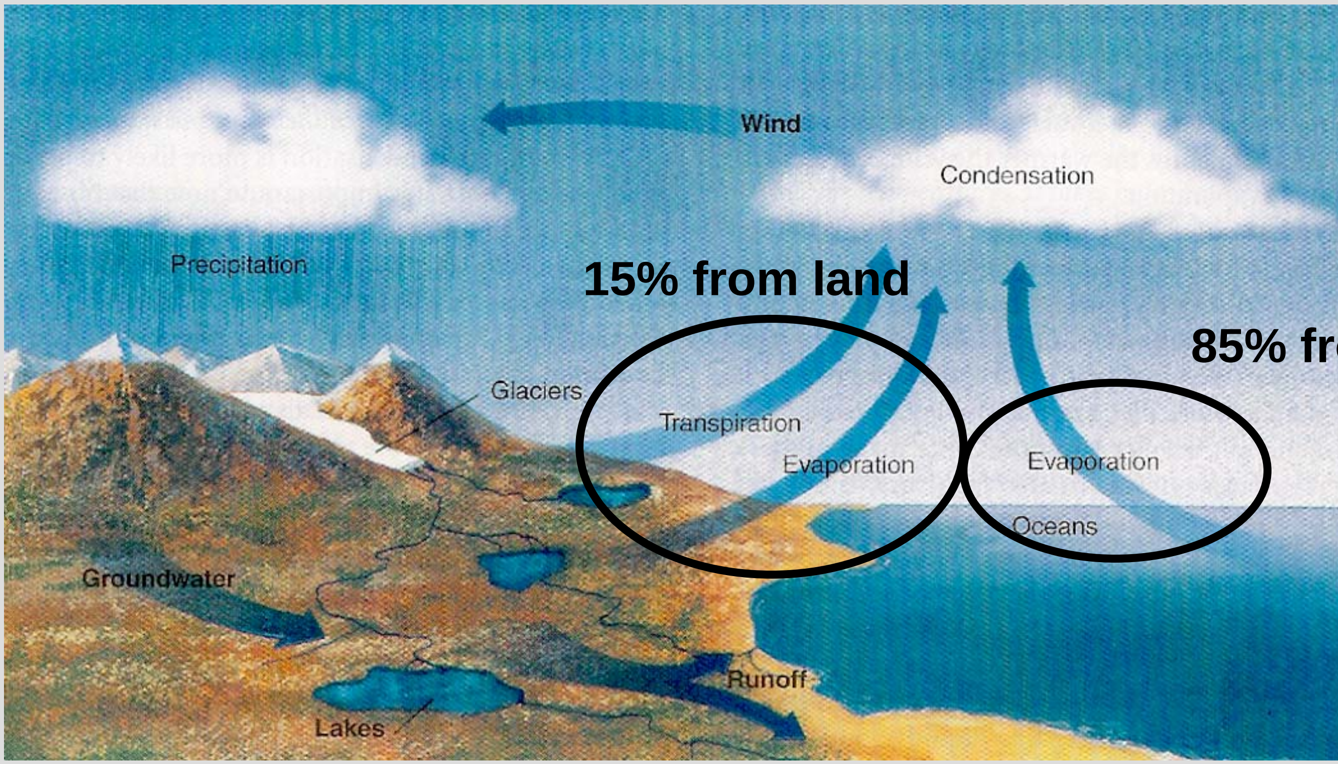
Atmospheric Moisture

The Hydrologic Cycle



Circulation of water through the land, atmosphere, and ocean through its three phases

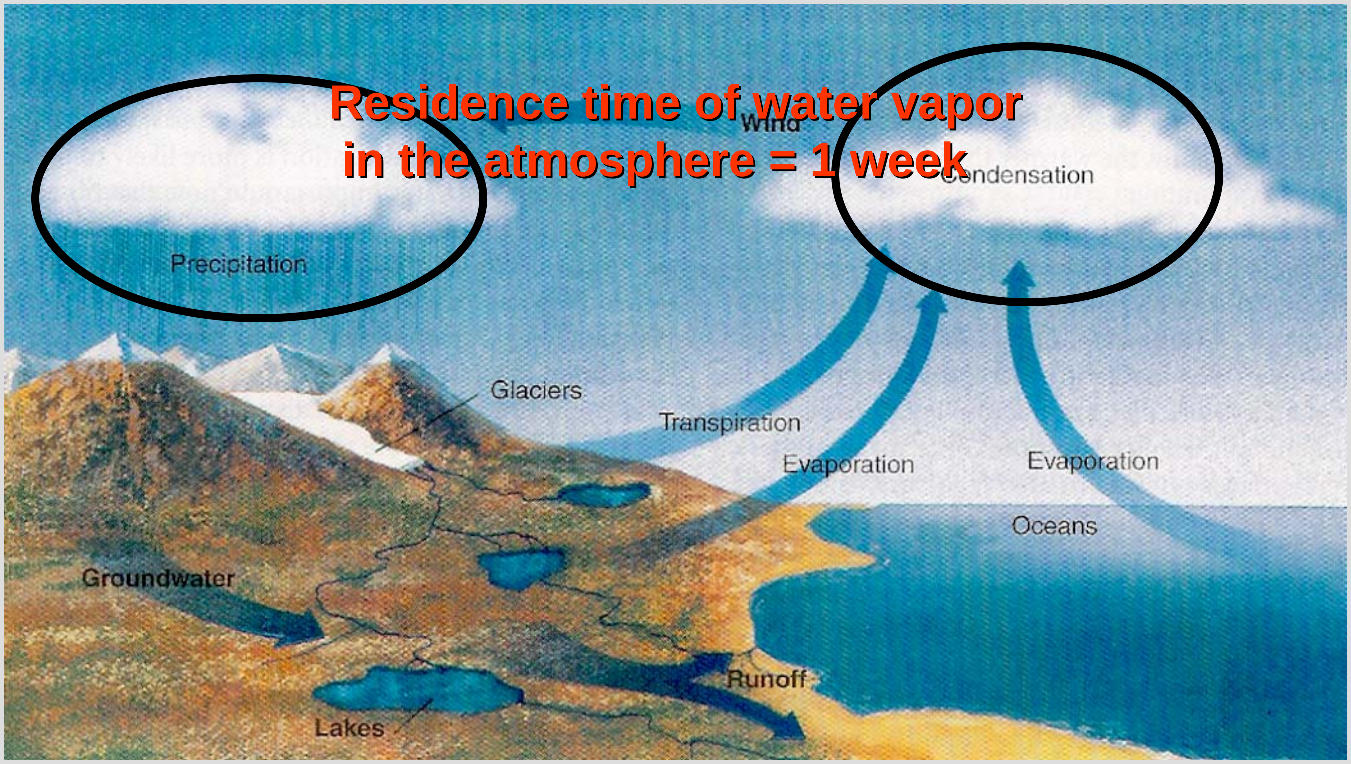
The Hydrologic Cycle: Evaporation and Transpiration



<u>Evaporation</u>: **Liquid water from land or water bodies converted in to water vapor.**

<u>Transpiration</u>: **Water vapor that is released by plants.**

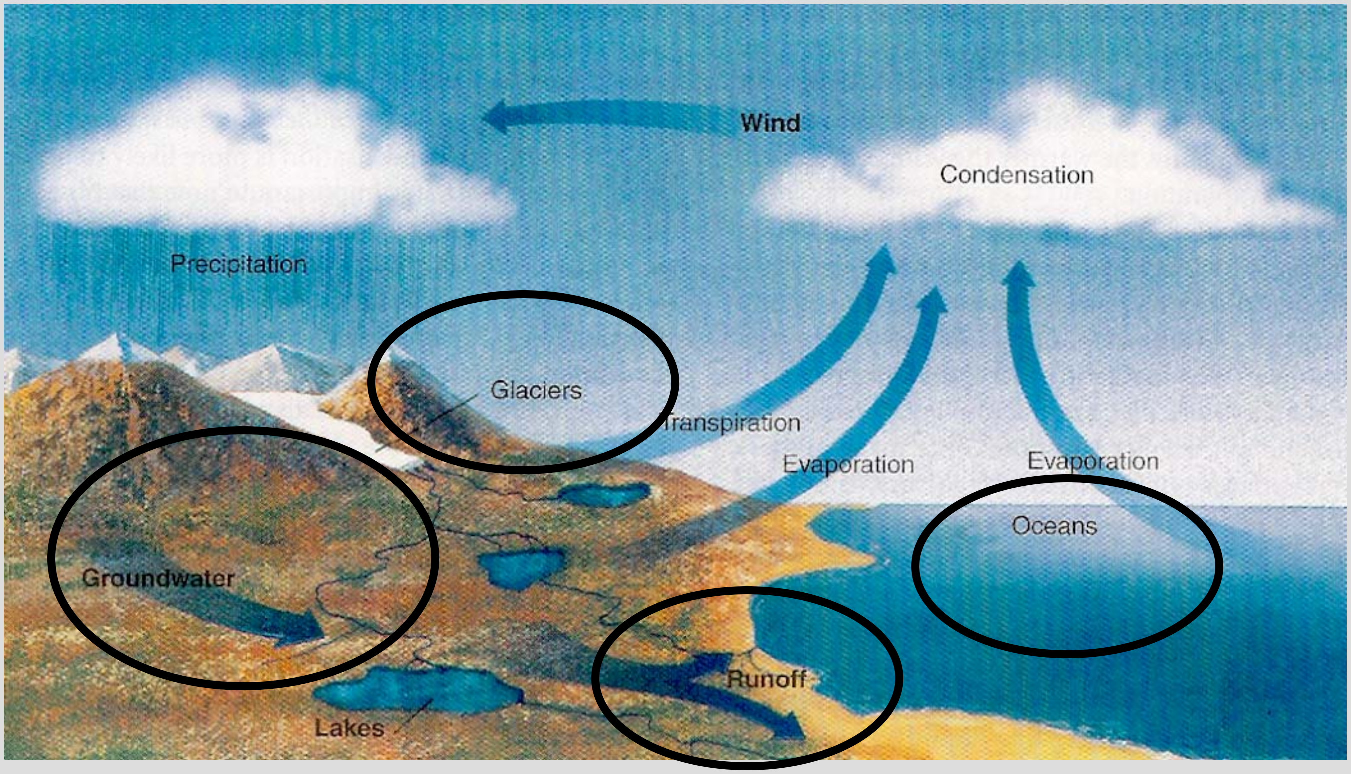
The Hydrologic Cycle: Condensation and Precipitation



Condensation: **Water vapor converted to liquid or solid to create clouds. This process does what? ____________________________**

Precipitation: **Liquid or solid water falls from clouds to the surface.**

The Hydrologic Cycle: Groundwater, Storage, and Runoff.



Groundwater: **Liquid water which infiltrates the soil**

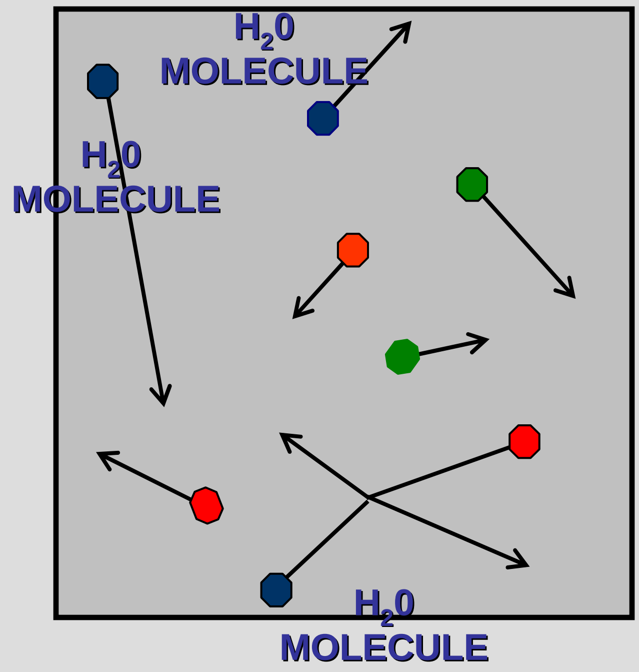
Storage: **Liquid or solid water stored in glaciers or water bodies.**

Runoff: **Surface liquid water transport to sea or ocean via rivers.**

Partial Pressure of Water Vapor

In a gas mixture, like air, the total pressure is the sum of it's partial pressures of it's different constituents.

The pressure due only to water vapor is called the vapor pressure (e).



$$P_{TOTAL} = P_{WATER\ VAPOR} + P_2 + P_3$$

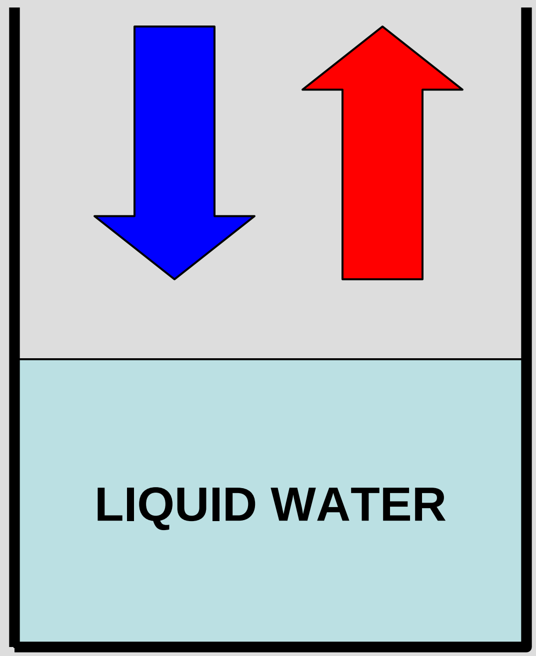
$$P_{WATER\ VAPOR} = e$$

The Concept of Saturation

At the interface between air and liquid water, water molecules are either:

Evaporating: Changing phase from liquid to gas

Condensing: Changing phase from gas to liquid

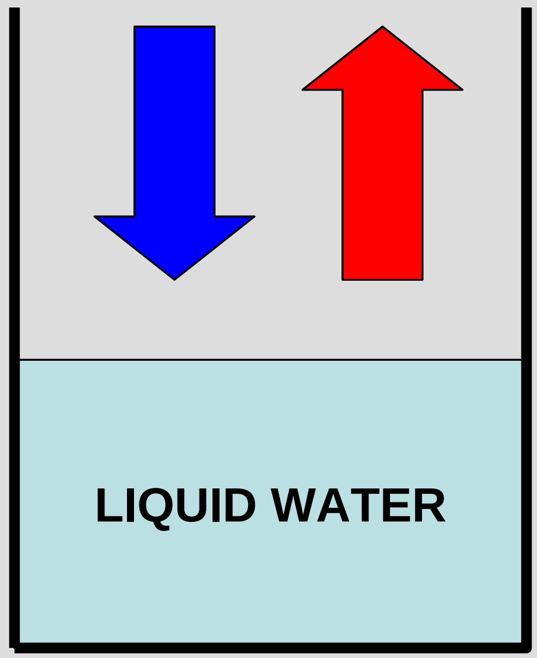


The Concept of Saturation
Evaporation = Condensation

Saturation vapor pressure = e_s

When the rate of evaporation equals the rate of condensation, the air is said to be *saturated* with respect to water vapor and can hold no more water

The amount of liquid water doesn't change.

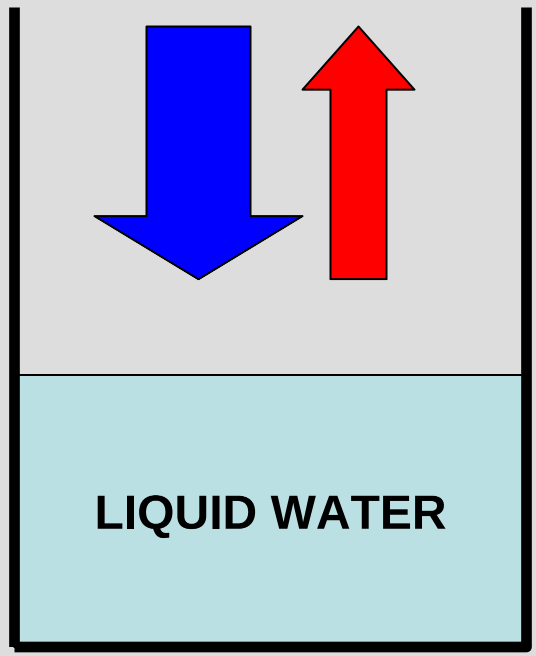


What is happening when liquid water condenses? Evaporation < Condensation

Supersaturated

$e > e_s$

More water molecules are changing phase from gas to liquid than changing phase from liquid to gas.



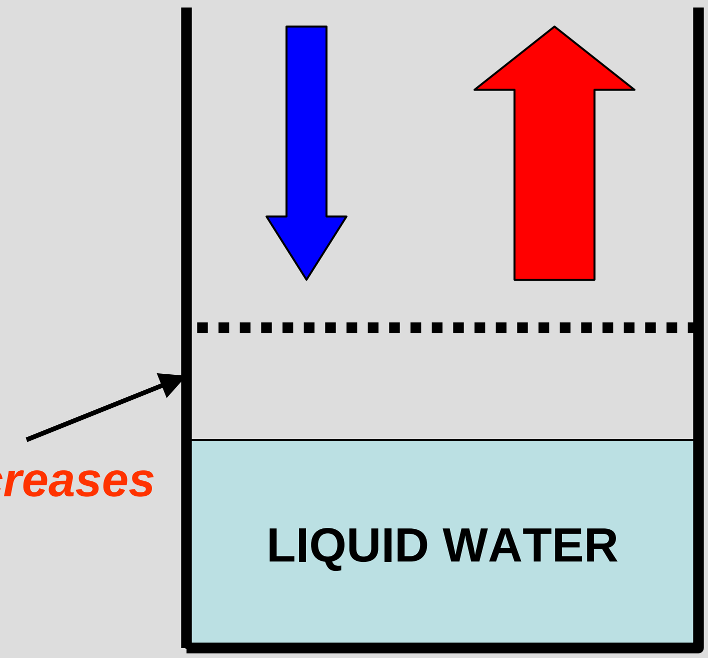
If the rate of evaporation < rate of condensation, the air is said to be *<u>supersaturated</u>* with respect to water vapor.

***This condition doesn't last too long*.**

What is happening when liquid water evaporates?
Evaporation > Condensation

Unsaturated
$e < e_s$

More water molecules are changing phase from liquid to gas than changing phase from gas to liquid.



Volume of liquid water decreases due to evaporation

If the rate of evaporation > rate of condensation, the air is said to be *unsaturated* with respect to water vapor. The amount of liquid water decreases.

Ways to increase evaporation

- Increase the ________________
- Increase the ________________
- Decrease the ________________.

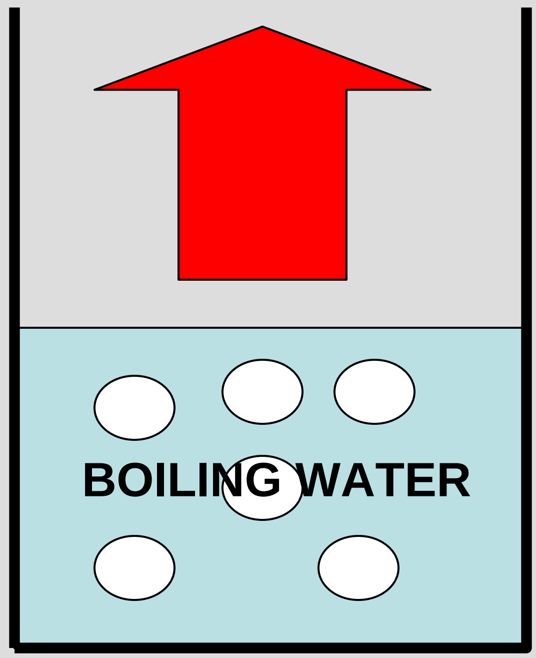
What is happening when liquid water is boiling?

The *boiling point* is defined where the vapor pressure is equal to the total atmospheric pressure.

The lower the total atmospheric pressure, the lower the boiling temperature.

How does this affect cooking time of boiling an egg, for example?

Boiling point
e = Total Atmospheric Pressure



Vapor pressure (e) vs. Saturation vapor pressure (e_s)

Saturation vapor pressure (e_s): **Maximum amount of water that the air at a given temperature can potentially hold. Doesn't change so long as temperature and pressure are constant.**

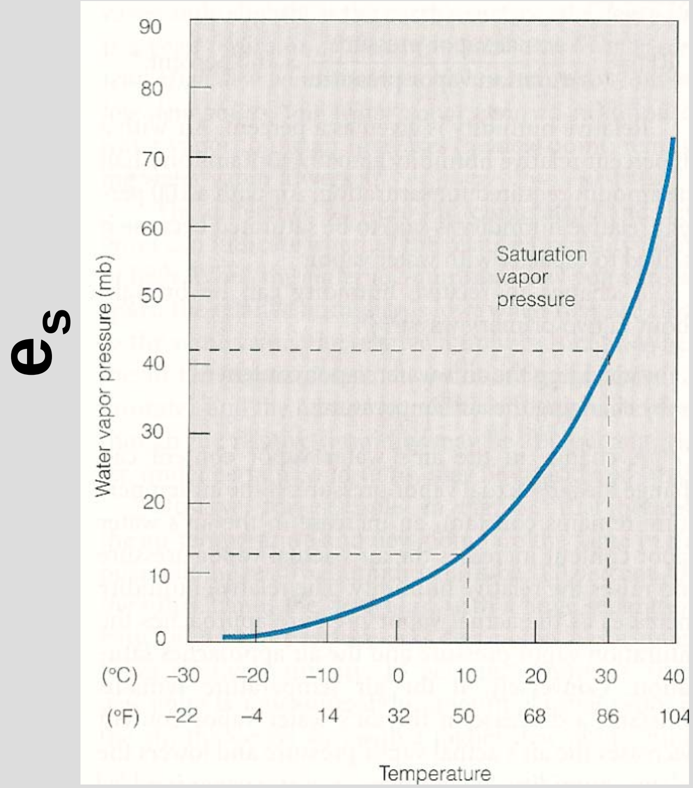
Vapor pressure (e): **Actual amount of water that the air holds**

The saturation vapor pressure increases nonlinearly with temperature.

0°C to 10°C → e_s increases by 10 mb

10° to 40°C → e_s increases by 30 mb

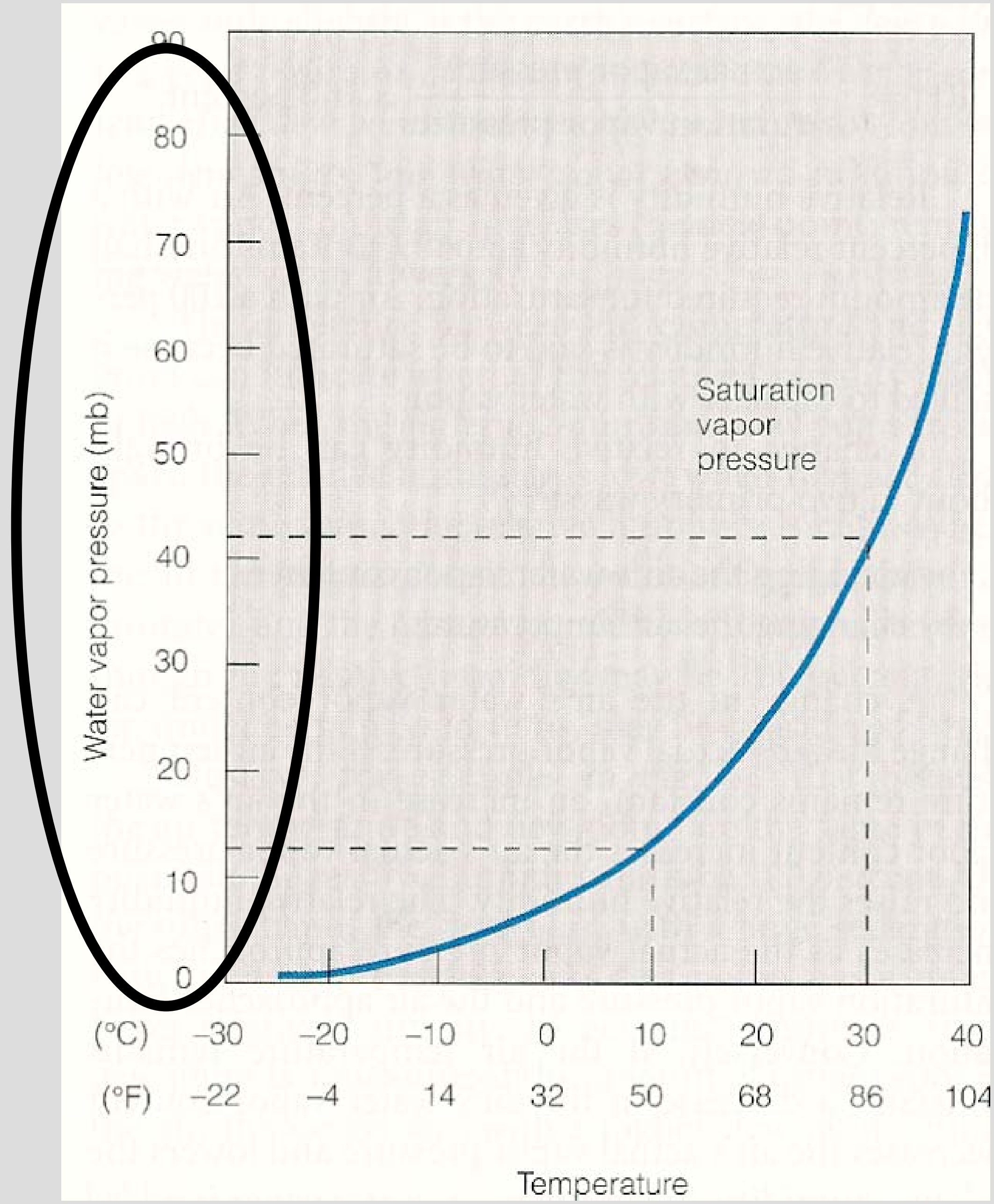
The warmer temperature, more water vapor the air can potentially hold.



Note the range in of water vapor pressure here…

It approximately is between 0 mb and 70 mb.

Compared to the average mean sea level pressure (1013 mb), water vapor can potentially contribute between 0 and 7% of the total atmospheric pressure.



Definition of Relative Humidity

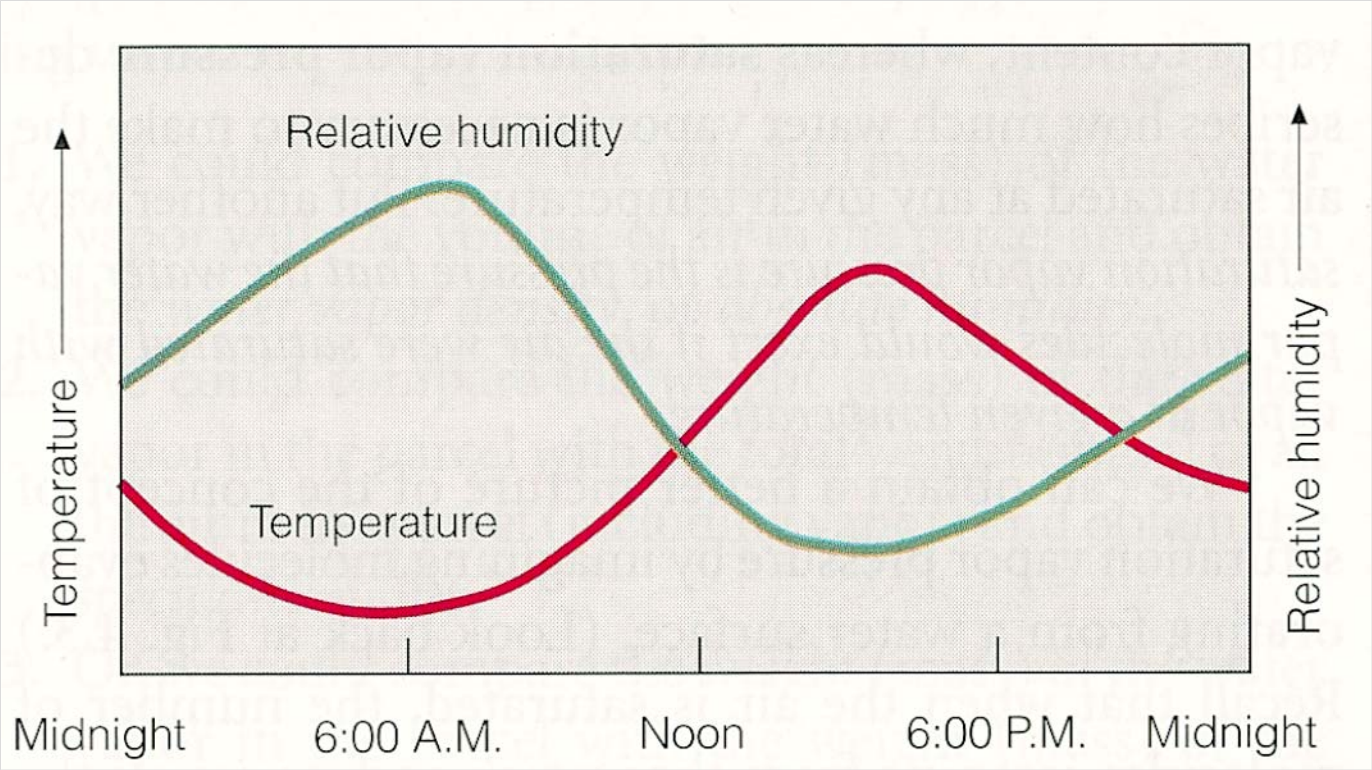
Ratio of the amount of water vapor in the air to the maximum amount of water vapor the air can potentially hold at the given temperature and pressure, or saturation vapor pressure. Typically expressed as percentage.

$$\text{Relative Humidity} = \frac{e}{e_s} \times 100\%$$

Saturated: $e = e_s$ and relative humidity = 100%

Unsaturated: $e < e_s$ and relative humidity < 100%

Relative Humidity depends on BOTH water vapor content and temperature



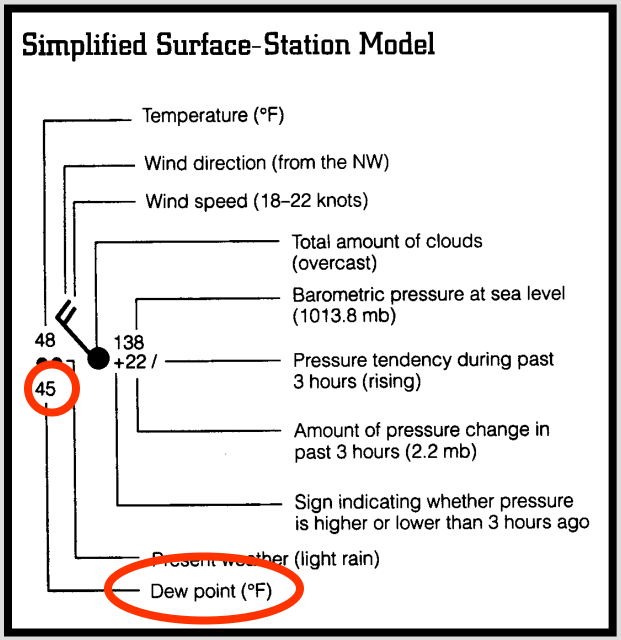
For an idealized diurnal cycle of temperature, the relative humidity will change—*even if the amount of water vapor in the air remains the same.*

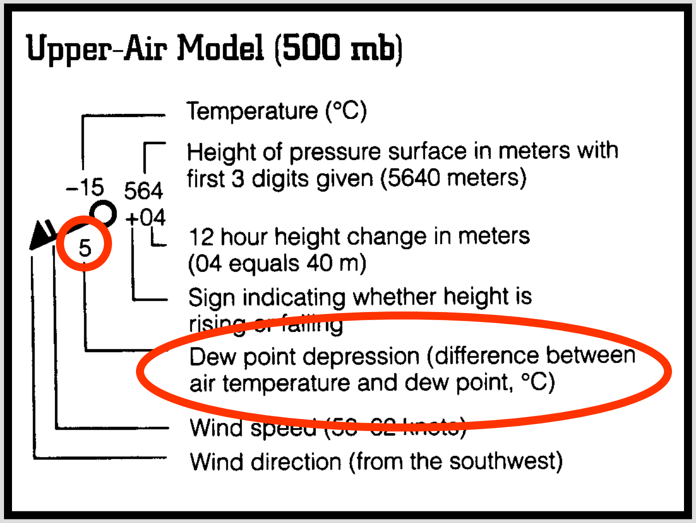
Definition of dew point temperature

Temperature at which air would have to be cooled in order for saturation to occur. When the air temperature equals the dew point, air is saturated.

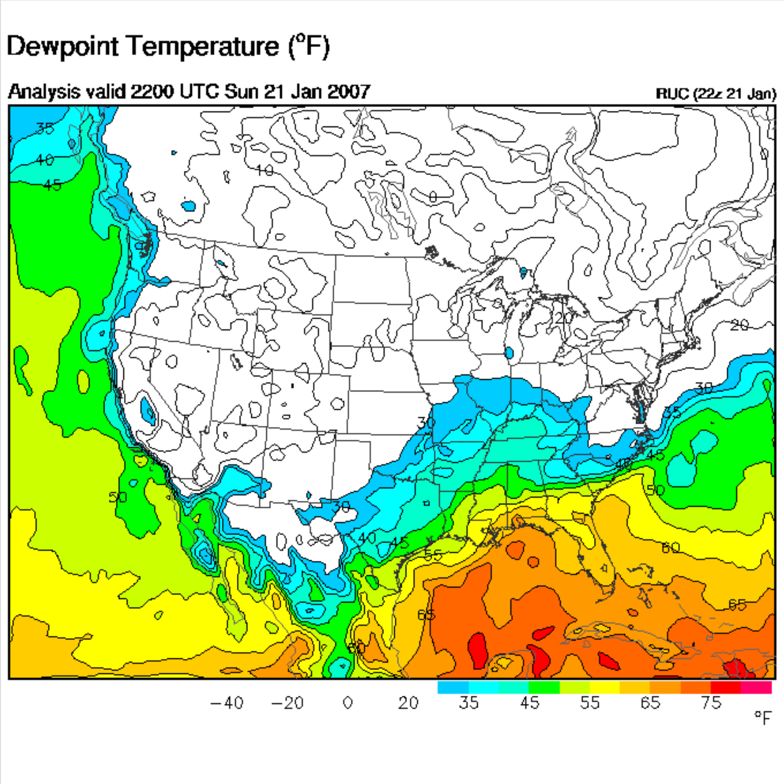
Unlike relative humidity, the dew point does not depend on the temperature. The higher the dew point, the higher the water vapor content and the vapor pressure (e).

Recall that the dew point is plotted in the surface and upper air station models





Dew point analysis
22 UTC (3 pm MST), 1-21-07
RUC Model from UCAR RAP Website



<u>Some climatological features to note</u>:

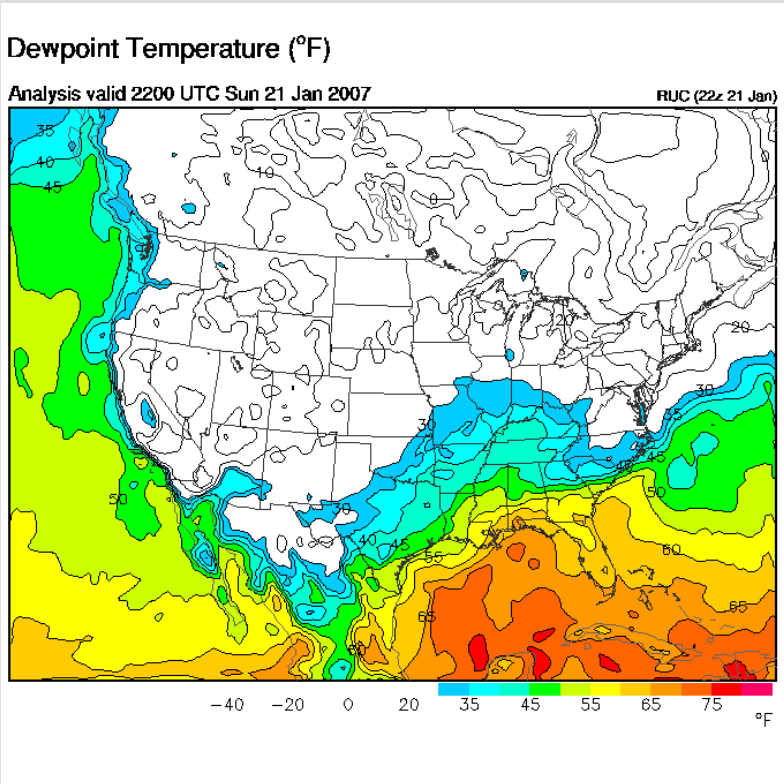
More water vapor over oceans.

The higher the water temperature, the higher the dew point. Note the difference between the Gulf of Mexico and the Pacific.

Because the Gulf of Mexico and Atlantic are warmer than the Pacific, typically more moisture is found in the eastern U.S.

Low dew point where it is very cold, such as Canada and northern U.S.

Dew point analysis
22 UTC (3 pm MST), 1-21-07
RUC Model from UCAR RAP Website



HOWEVER, there is something quite climatologically atypical happening on this day in our part of the world!

Southern Arizona has a fairly high dew point (35°F) compared to its typical climatological value for January (20°F).

Surface Station Model for Tucson (TUS)
3 pm MST, 1-21-07

What are the weather conditions here from the station model?

…And a bit later that day around 5 pm

Why is this a very atypical surface weather observation for Tucson?

Other measures of atmospheric moisture

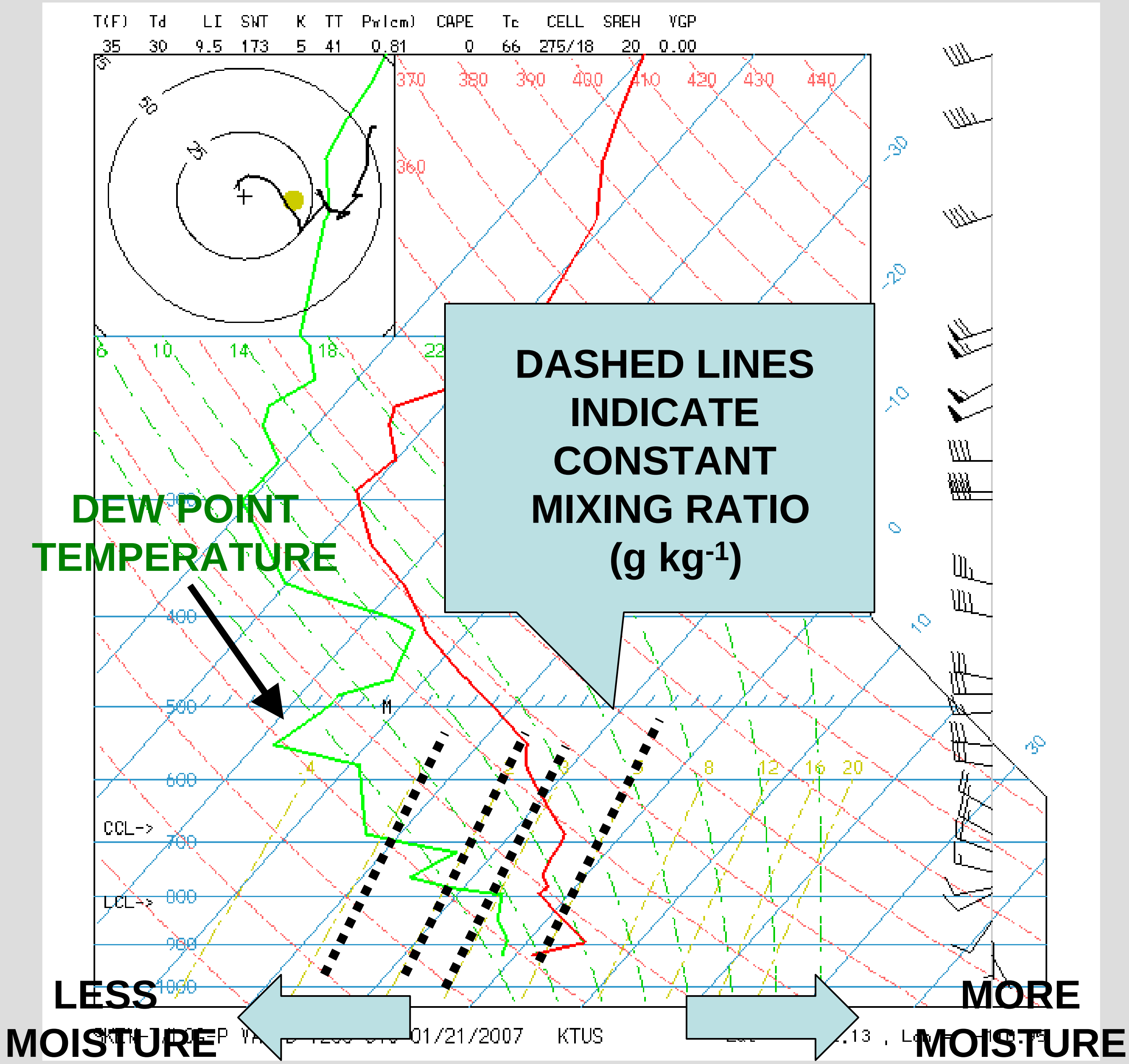
$$\text{Specific Humidity} = \frac{\text{mass of water vapor (g)}}{\text{total mass of air (kg)}}$$

$$\text{Mixing Ratio} = \frac{\text{mass of water vapor (g)}}{\text{mass of dry air (kg)}}$$

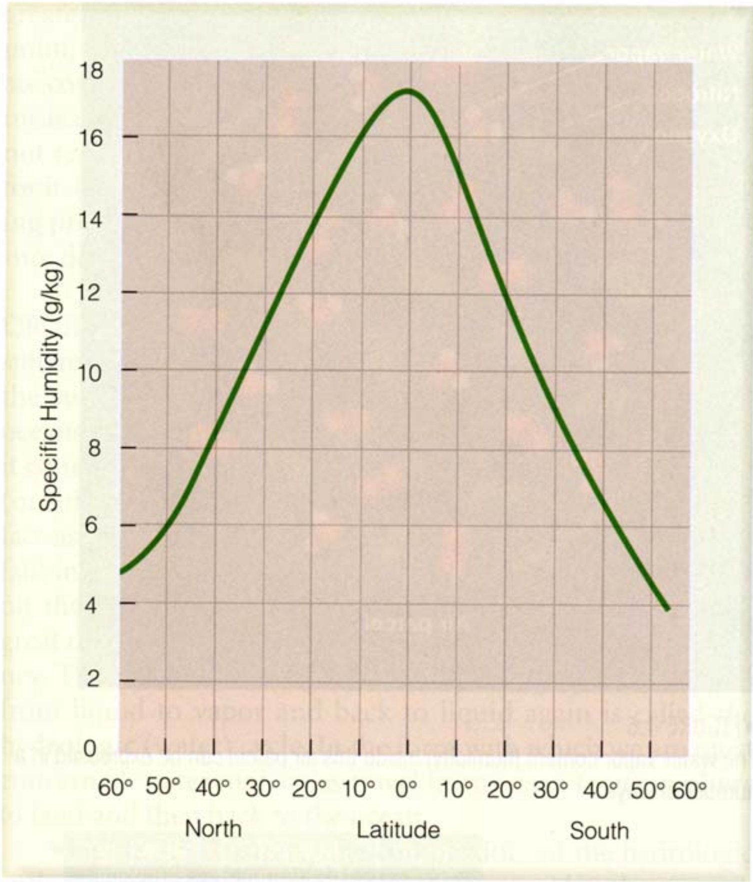
Measures typically given in grams per kilogram

Atmospheric Moisture and Skew-T, Log P Diagram

TUSCON SOUNDING FOR 1-21-07



Latitudinal Average Specific Humidity for the Globe



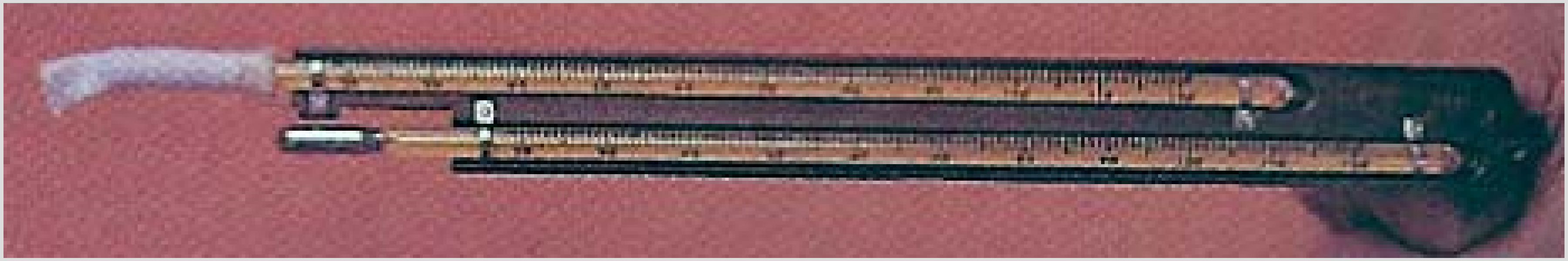
• FIGURE 4.9
The average specific humidity for each latitude. The highest average values are observed in the tropics and the lowest values in polar regions.

Low latitudes: Highest specific humidity because temperatures are warmest

High latitudes: Lowest specific humidity because temperatures are coldest

Wet Bulb Temperature
(one more measure of moisture!)

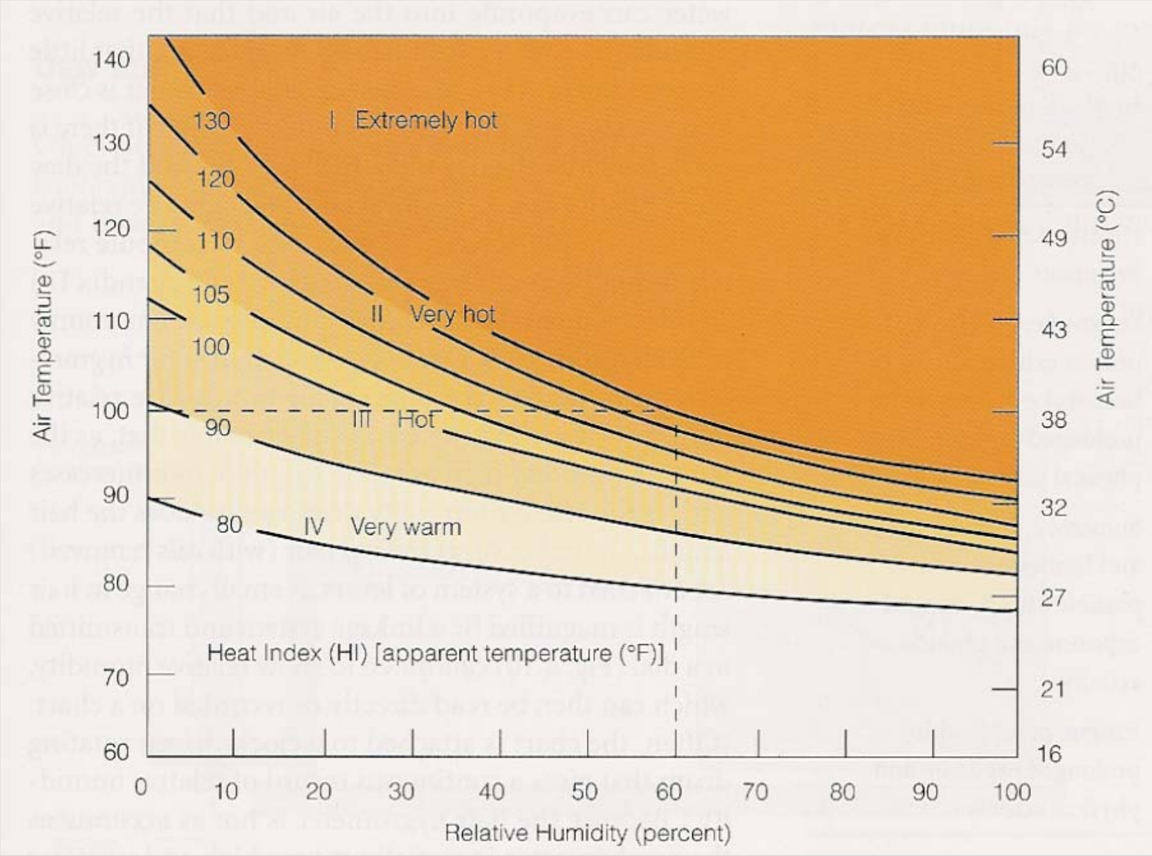
Lowest temp to which air can be cooled by evaporation of water into it. Warmer than dew point since moisture is being added to air which raises dew point.



Wet bulb temperature is measured with a sling psychrometer.

A comprehensive list conversion table for all the humidity measures we've talked about today can be found in Appendix D of Ahrens.

Heat Index: What the air "feels" like with a given relative humidity



<u>Idea behind it</u>:

More humid the air is, the more difficult it is for the sweat generated by your body to cool you down.

Wind Chill: What the air “feels” like with a given wind speed

TABLE 3.2 Wind-Chill Equivalent Temperature (°F). A [illegible]-mi/hr Wind Combined with an Air Temperature of 20°F Produces a Wind-Chill Equivalent Temperature of 4°F.

WIND SPEED (MI/HR)	AIR TEMPERATURE (°F)																
Calm	40	35	30	25	20	15	10	5	0	−5	−10	−15	−20	−25	−30	−35	−40
5	36	31	25	19	13	7	1	−5	−11	−16	−22	−28	−34	−40	−46	−52	−57
10	34	27	21	15	9	3	[illegible]	−10	−16	−22	−28	−35	−41	−47	−53	−59	−66
15	32	25	19	13	6	0	−7	−13	−19	−26	−32	−39	−45	−51	−58	−64	−71
20	30	24	17	11	4	−2	−9	−15	−22	−29	−35	−42	−48	−55	−61	−68	−74
25	29	23	16	9	3	−4	−11	−17	−24	−31	−37	−44	−51	−58	−64	−71	−78
30	28	22	15	8	1	−5	−12	−19	−26	−33	−39	−46	−53	−60	−67	−73	−80
35	28	21	14	7	0	−7	−14	−21	−27	−34	−41	−48	−55	−62	−69	−76	−82
40	27	20	13	6	−1	−8	−15	−22	−29	−36	−43	−50	−57	−64	−71	−78	−84
45	26	19	12	5	−2	−9	−16	−23	−30	−37	−44	−51	−58	−65	−72	−79	−86
50	26	19	12	4	−3	−10	−17	−24	−31	−38	−45	−52	−60	−67	−74	−81	−88
55	25	18	11	4	−3	−11	−18	−25	−32	−39	−46	−54	−61	−68	−75	−82	−89
60	25	17	10	3	−4	−11	−19	−26	−33	−40	−48	−55	−62	−69	−76	−84	−91

Idea behind it:

Heat is more rapidly removed by constant bombardment of cold air. So faster the wind blows colder you feel.

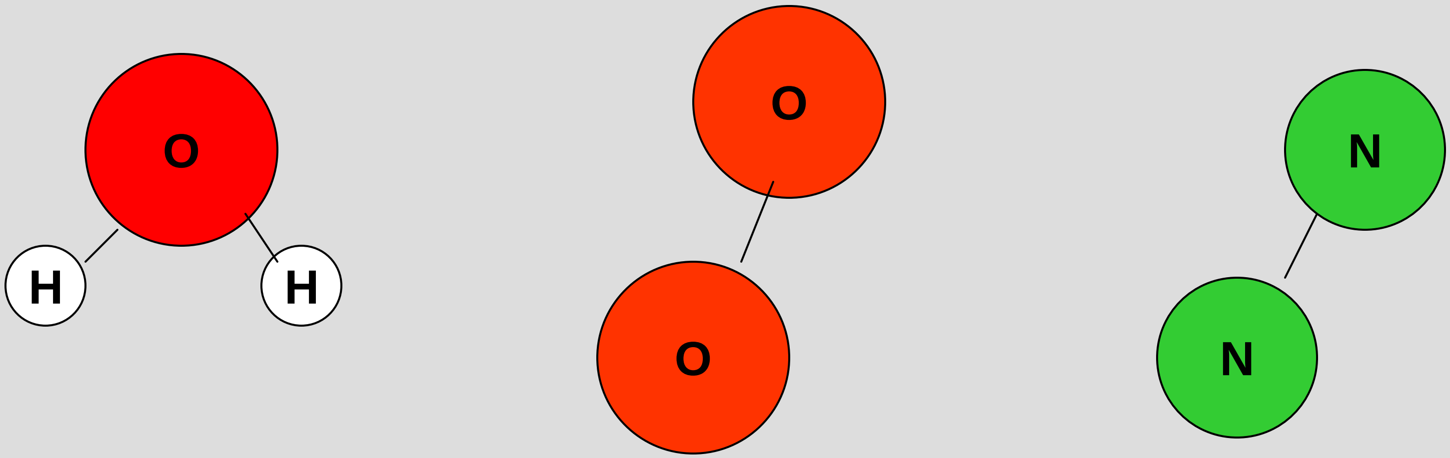
A higher wind speed also would increase evaporation as well.

Frostbite occurs in 30 minutes or less!

Finally, let's dispel the common myth that humid air is heavier than dry air.

Why is this not the case?

Molecular Weight of Water vs. Oxygen and Nitrogen



WATER (H_2O)
18 g per mole

OXYGEN (O_2)
32 g per mole

NITROGEN (N_2)
28 g per mole

Increasing the humidity increases the partial pressure due to water vapor, which is actually lighter than oxygen or nitrogen. Therefore, more humid air is _______________

Summary of Lecture 9

The hydrologic cycle describes the circulation of water in its three phases through the land, atmosphere, and ocean.

Air is saturated when the rate of condensation = rate of evaporation. The saturation vapor pressure defines the maximum amount of water that air at a given temperature can hold—and it increases non-linearly with temperature.

Air is unsaturated when the rate of evaporation exceeds the rate of condensation. The evaporation can be increased by increasing temperature, increasing wind speed, or decreasing relative humidity.

Relative humidity is the ratio of the vapor pressure to the saturation vapor pressure, so it depends on water vapor and temperature.

Dew point is the temperature at which air would have to be cooled in order to reach saturation.

Other measures of atmospheric moisture are specific humidity, mixing ratio, and wet bulb temperature.

Heat index and wind chill indicate how the air “feels” due to humidity and wind, repectively.

Reading Assignment

Chapter 5: pp. 107-117 (8^{th} ed.)
pp. 112-121 (9^{th} ed.)