Chapter 3 Water, Humidity, Fog Objectives

- Appreciate the significance of the Earth's water cycle.
  - water plays an important role in Earth's weather
- Understand water's phase changes and latent heat.
- Be familiar with humidity and how it is measured.
- Understand the causes and different types of fog.
- Appreciate the dangers posed by floods and how to avoid them.

FUTURE LLI WEATHER COURSES

- Future Classes to cover these topics
  - FALL 2020
  - Thunderstorms, Tornadoes, Lightning, Optical Effects
  - SPRING 2021
  - Mid-latitude weather and storms
  - Tropical Weather and Storms, Hurricanes
  - Weather forecasting processes and resources

What causes “Weather?”

The “Prime Directive” on Weather

The source of all weather on Earth is unequal heating of the Earth’s surface by the Sun.

- **It’s all about the sun**
  - **Heat from the sun is absorbed:**
    - **by the air**
    - **by the water**
    - **by the land**
- **and, Water vapor…**
  - **We will learn more about water and water vapor in this class**

Recap Chapter One, Class 1

- **Temperature generally decreases as altitude increases throughout the lower atmosphere** **Weather**

- **Temperature is a measure of relative hotness or coldness and is a very important factor in weather.**

- **Heat is energy transferred from a warmer to a cooler body.**

- **Heat is transferred in three ways: conduction, convection, and radiation.**

  - "**convection**" to refer to up and down motions of air.

  - "**advection**" to refer to horizontal movement of air.

- **Specific Heat is the measure of the amount of heat it takes to change the temperature of a substance. Water has a very high specific heat compared to metals, and dry land.**

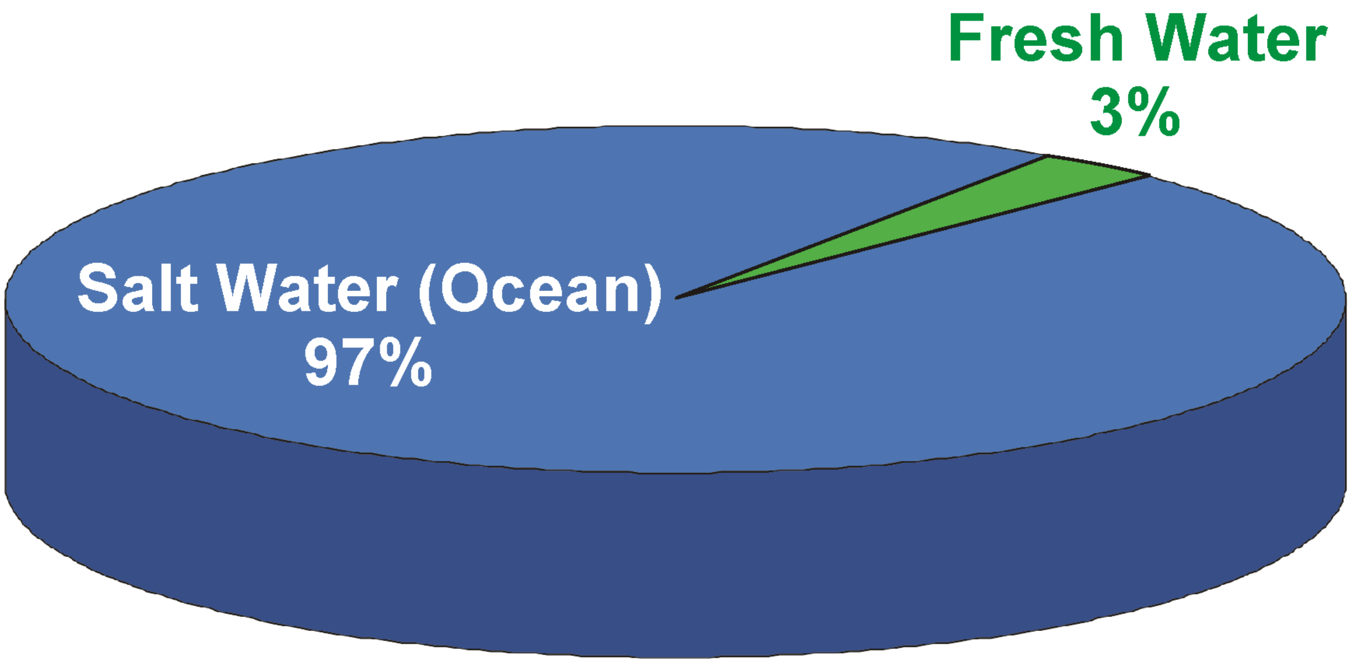
- **The term lapse rate is the observed temperature change as altitude changes in the atmosphere.**

- **Inversions are important factors in determining atmospheric conditions often contributing to haze and smog.**

Recap of Chapter Two, Class 1

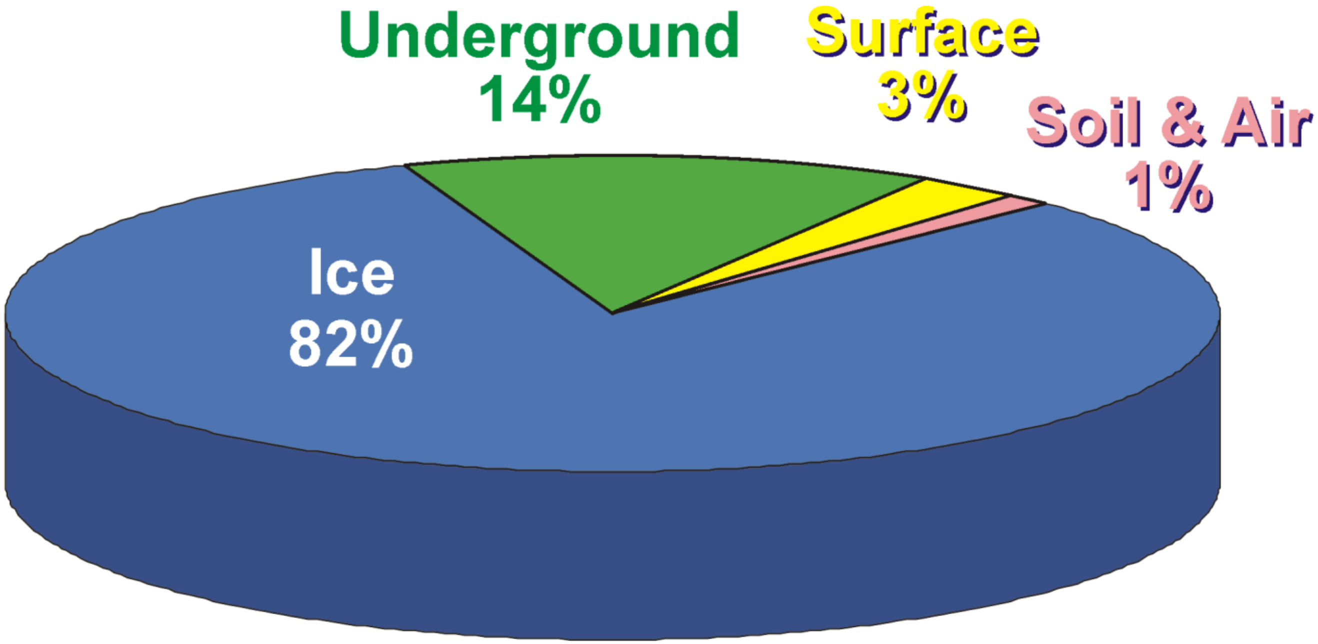
- **Convective circulation of winds from temperature differences due to uneven heating of Earth's surface creates atmospheric circulation with distinct alternating low and high pressure regions in the northern and southern hemisphere**
- **Winds result from a Pressure Gradient Force that is modified by friction and coriolis forces with the result winds are turned to right in northern hemisphere**
- **We learned how to recognize where a low pressure is located (Buy's Balot: face wind and extend right arm and that points to low pressure area)**
- **We learned that in the northern hemisphere, winds circulate counterclockwise (cyclonic) for a low pressure system, and clockwise (anticyclonic) for a high pressure system.**
- **Ideal Gas Law PV= n RT or to simplify PV ~ nT**
  - **NOTE: R is the Universal Gas Constant**

Earth’ s Water
is 71% of Earth’s surface area

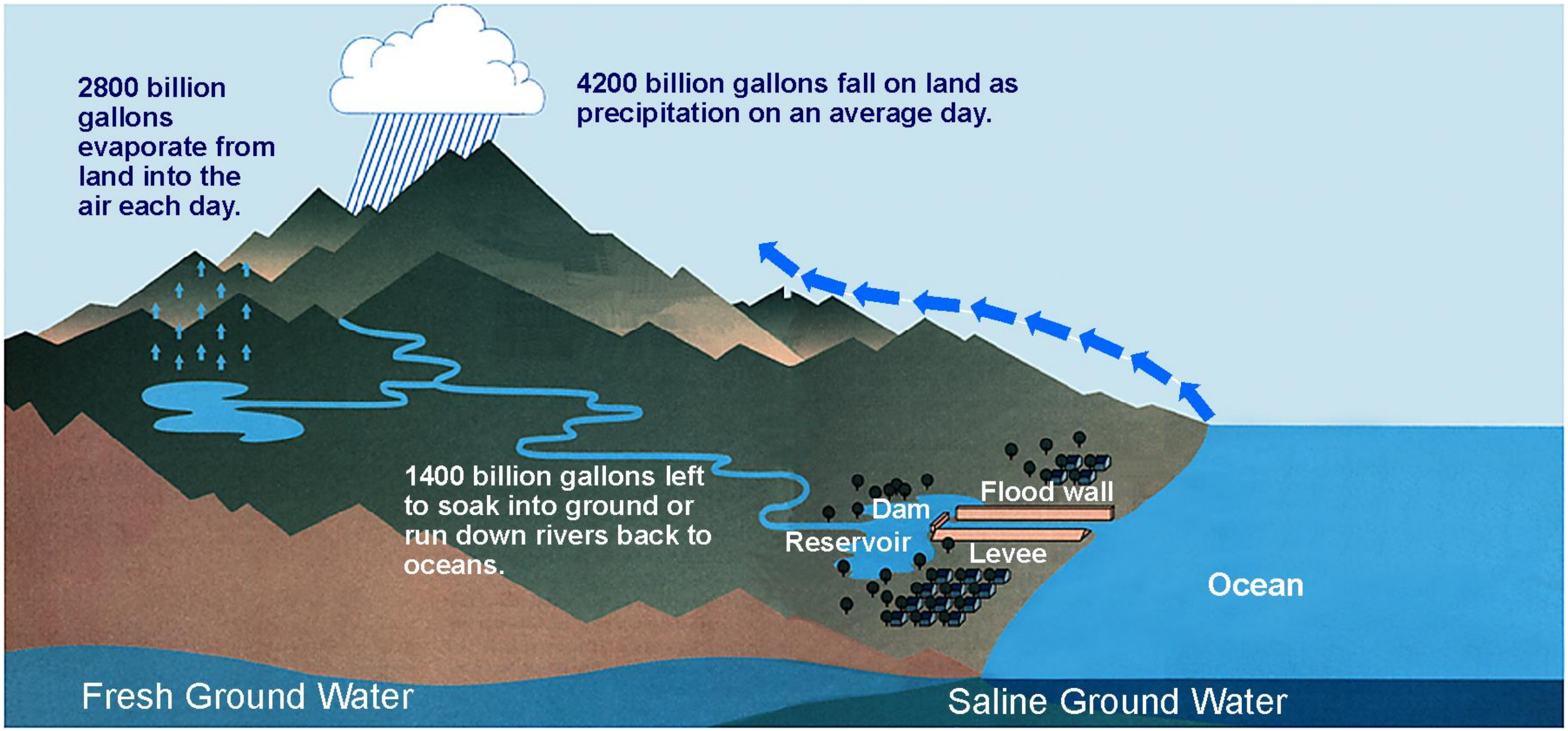


When **sea water evaporates most of the salt is left behind**. The salt-free water vapor condenses in the atmosphere and becomes rain and/or snow. **Icebergs are mostly freshwater** and as ice is less dense than water they float on the ocean.

Earth's Freshwater (3% of total)



Hydrological Cycle



Interesting Factoids

•average day, **40,000 billion gallons of water are in the atmosphere over the U.S. as water vapor or liquid water and ice in clouds.** (Imagine this as the water in an average-sized, 40-gallon bathtub.). This would represent 4.2 gallons drained out by rain and 2.8 gals evaporate back into atmosphere. **The atmosphere, or the tub, never runs dry because water evaporating from the oceans and carried by winds over land makes up the difference.**

Water in the Air

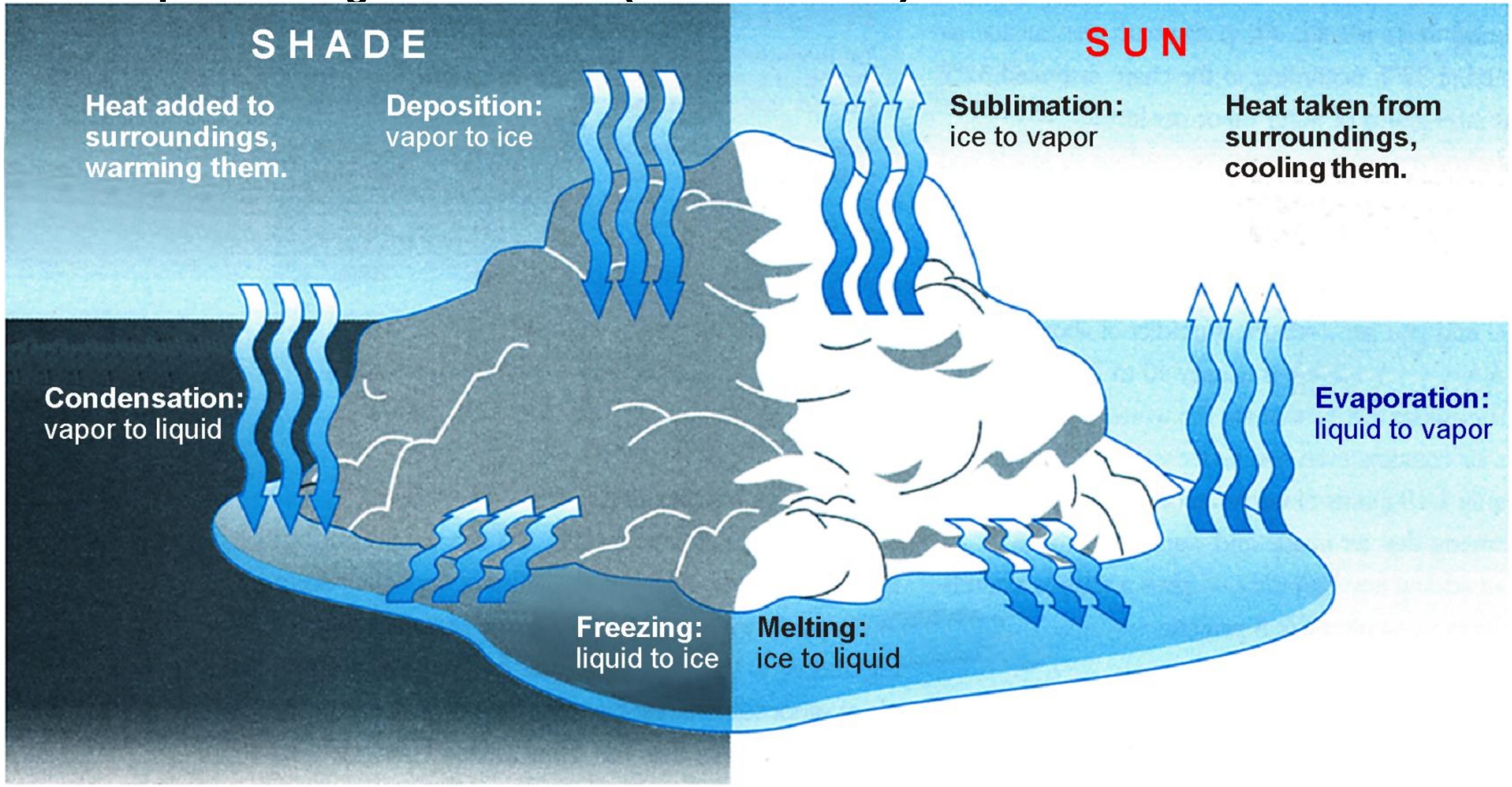
- **Water (H_2O) in the air exists as a solid, a liquid, and a gas.**
- **Solid – hail, sleet, ice, and ice crystals in snow and clouds**
- **Liquid – rain, fog and cloud droplets**
- **Gas – water vapor (steam, humidity in atmosphere)**

Water Vapor in the Air

- Water Vapor is an invisible and odorless gas.
- The amount of water vapor in the air ranges
  - from less than 1% (very dry air-deserts)
  - to 4% (very moist air-tropical).
- Water vapor is lighter (less dense --less mass/volume) than air.
- Humid air is lighter than dry air.

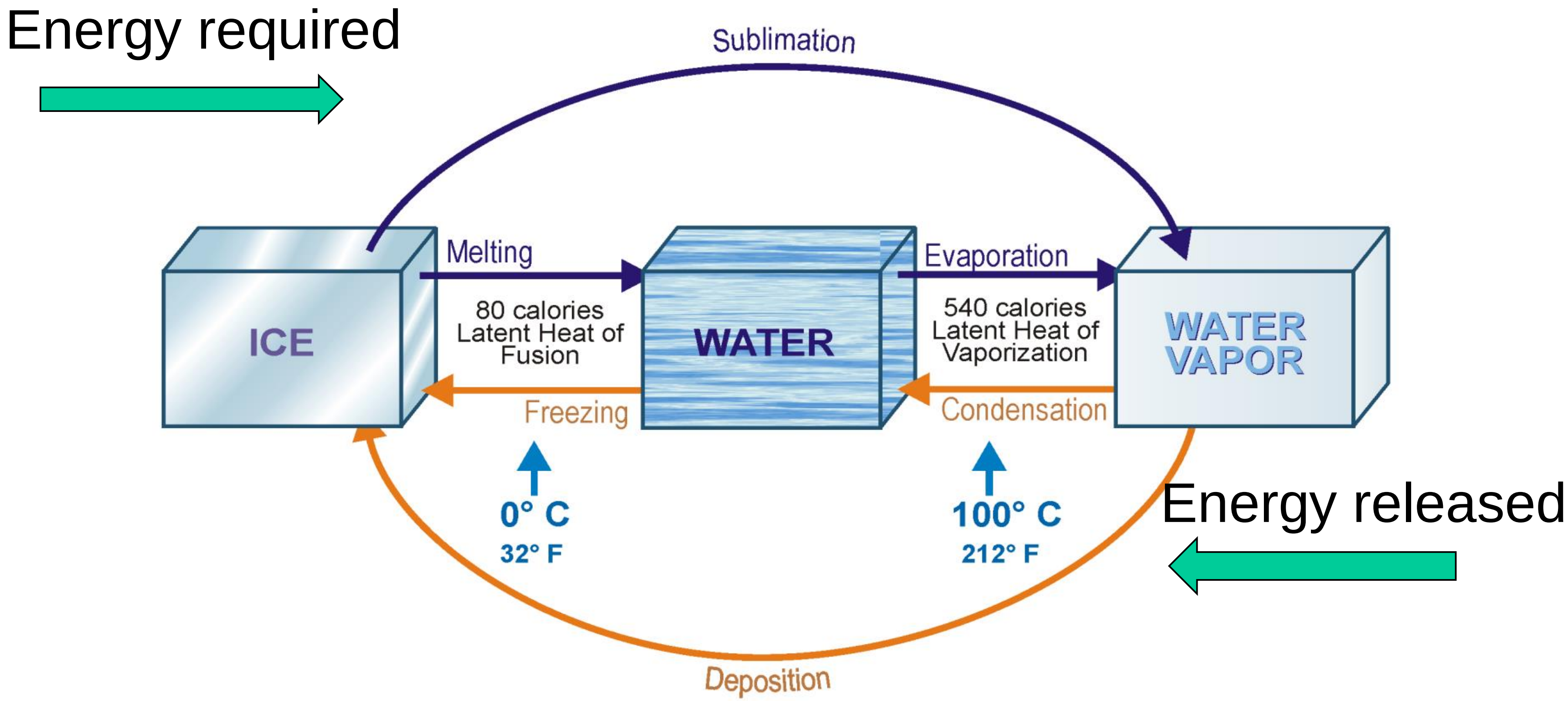
Water Phase Changes: six processes

1. Evaporation: liquid to a gas (requires heat)-doesn't increase temp but stored as potential energy-supplies energy for thunderstorms and hurricanes
2. Condensation: gas to a liquid (releases heat)
3. Melting: solid to a liquid (requires heat)
4. Freezing: liquid to a solid (releases heat)
5. Sublimation: solid to a gas (requires heat)
6. Deposition: gas to a solid (releases heat)



Change of State - Latent Heat

the amount of energy needed to change a substance from one state to another. It can be thought of as "potential energy" stored within chemical bonds of molecules



Latent heat-important source of energy in fueling Earth's thunderstorms and hurricanes

Latent Heat of Various Substances

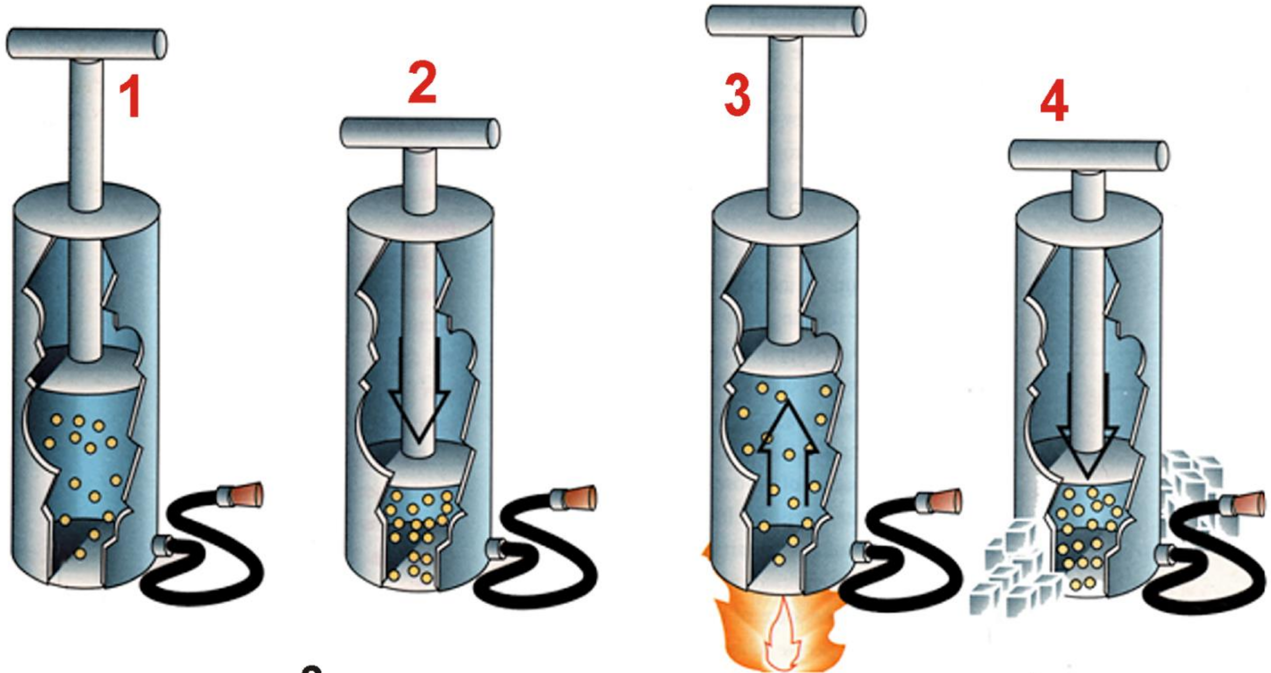
Substance	Specific latent heat of fusion $J.g^{-1}$	°C	Specific latent heat of vaporization $J.g^{-1}$	°C
Water	334	0	2258	100
Ethanol	109	-114	838	78
Ethanoic acid	192	17	395	118
Chloroform	74	-64	254	62
Mercury	11	-39	294	357
Sulphur	54	115	1406	445
Hydrogen	60	-259	449	-253
Oxygen	14	-219	213	-183
Nitrogen	25	-210	199	-196

Note how high water is compared to other substances

Air: Heated, Cooled, Under Pressure

An example of General Gas Law

General Gas Law: $\underline{PV / T} = \underline{P' V' / T'}$



1.

Pump's plunger won't fall all the way down since air pressure under it applies upward force, holding it up.

2.

Push down on plunger - squeezes molecules below together - air pressure under plunger increases - let go and this pressure pushes plunger back up.

3.

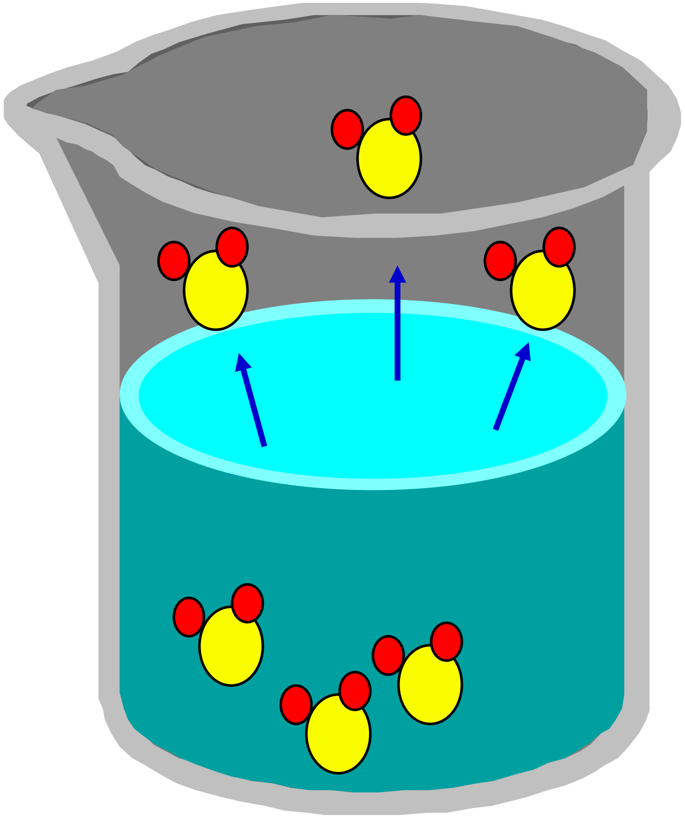
Heat pump's bottom - heat makes air molecules move faster, increasing pressure - plunger rises.

4.

Cool off pump - air molecules slow down - pressure decreases - plunger falls.

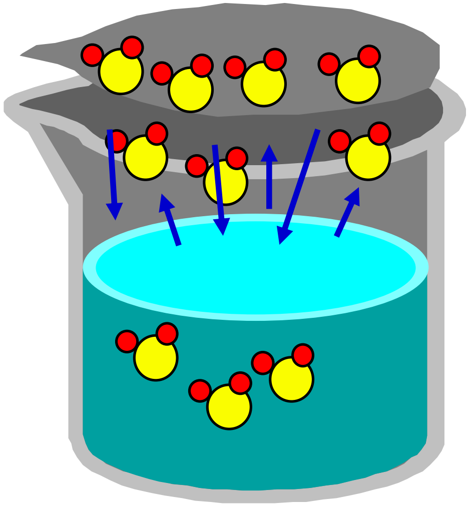
Unsaturated Air (no heat added or removed—constant T)

Water molecules are always moving. Temperature is based on the average kinetic energy (hence the average speed) of molecules in a substance.
But this molecular speed is only an average – some molecules are going faster and will jump from the air to liquid water and from liquid water into the air. When the air is unsaturated, however, more liquid molecules jump from liquid into the air than jump the other way – this is evaporation.



Saturated Air (no heat added or removed—constant T)

When the same number of liquid molecules jump from a liquid into the air as those that jump the other way - The air is saturated with water vapor.
A short-hand expression is to say the "air can not hold anymore water".
If you cool a volume of saturated air, some water vapor will be removed by condensation–the air is still saturated–but it is capable of holding less moisture at a lower temperature. If you warm a saturated volume of air, the air will no longer be saturated. Warmed air has greater moisture capacity.



Humidity

- **Humidity is a measure of the amount of water vapor in the air.**
- **Relative Humidity and Dew Point depend upon the concept of saturation**
- **Three ways of measuring humidity are:**
  - **Mixing Ratio- not discussed in this class primarily of interest to Meteorologists.**
  - **Relative Humidity: the percentage of actual water vapor in the air compared to what the air could hold at saturation. The actual amount of water vapor compared to what the maximum amount of water vapor the air could hold.**
  - **Dew Point the temperature at which the air is fully saturated and condensation begins**

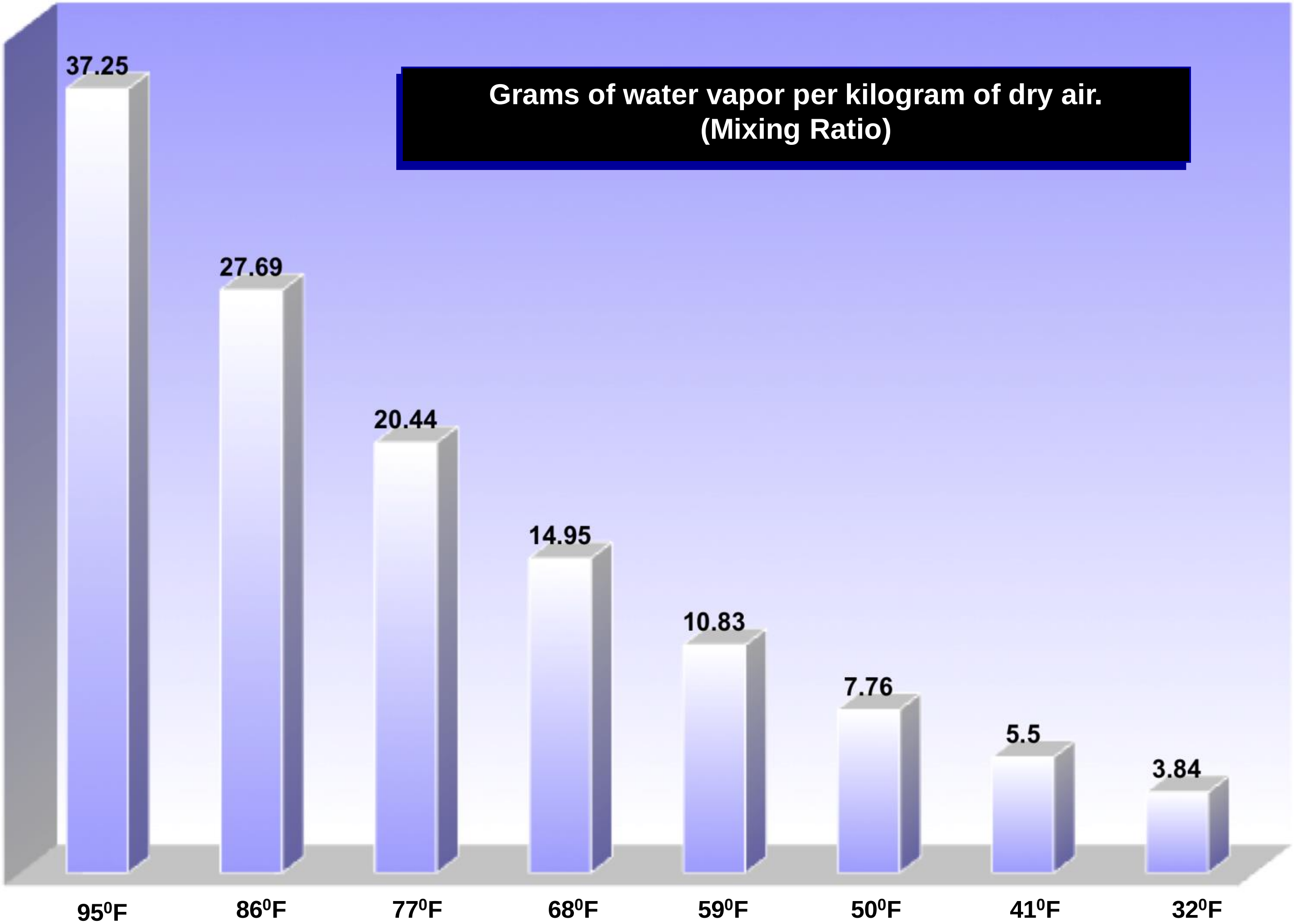
Water Vapor and Humidity

- At a fixed air temperature, the higher the water vapor content the greater the humidity.
- When water vapor is added to the air (evaporation):
  - The Relative Humidity goes up because the air is closer to being saturated; and
  - The Dew Point goes up because saturation will occur (and condensation will begin) at a higher air temperature.
- When water vapor leaves the air (condensation):
  - The Dew Point goes down.
- The Dew Point Spread is the difference between the air temperature and the Dew Point.
- The smaller the Dew Point Spread – the more likely condensation (e.g., fog) will occur.
  - When Dew Point = local temp fog will form

Air Temperature and Humidity

- **For a given amount of water vapor, the higher the air temperature:**
  - **the more additional water vapor is needed to reach saturation.**
  - **the lower the Relative Humidity.**
  - **the Dew Point does NOT change.**
  - **the Dew Point Spread increases (the difference between the air temp and the Dew Point).**
  - **Dew Point “spread” = Air Temp. – Dew Point**

Saturation Amounts
warm air holds more moisture then cold air



Relative Humidity

the same quantity of water vapor has higher humidity at lower temperatures

Temperature of the Air	Vapor Air Can Hold	Vapor Actually in the Air	Relative Humidity
86° F	27.6	10.83	39%
77° F	20.4	10.83	53%
68° F	14.9	10.83	72%
59° F	10.8	10.83	100%

Conversely: cold air holds less water vapor than warm air. We know this in the Winter!

HUMID AIR IS LESS DENSE THAN DRY AIR
From Essentials of Meteorology, by Ahrens and Henson, 8th Edition, p 90

Humid Air and Dry Air Do Not Weigh the Same

Does a volume of hot, humid air really weigh more than a similar-size volume of hot, dry air? The answer is no! At the same temperature and at the same level in the atmosphere, hot, humid air is lighter (less dense) than hot, dry air. This is because a molecule of water vapor (H_2O) weighs appreciably less than a molecule of either nitrogen (N_2) or oxygen (O_2). (Keep in mind that we are referring strictly to water vapor—a gas—and not suspended liquid droplets.)

Consequently, in a given volume of air, as lighter water vapor molecules replace either nitrogen or oxygen molecules one for one, the number of molecules in the volume does not change, but the total weight of the air becomes slightly less. Since air density is the mass of air in a volume, the more humid air must be lighter than the drier air. Hence, *hot, humid air at the surface is lighter (less dense) than hot, dry air.*

This fact can have an important influence in the weather. The lighter the air becomes, the more likely it is to rise. All other factors being equal, hot, humid (less-dense) air will rise more readily than hot, dry (more-dense) air (see ● Fig. 1). It is, of course, the water vapor in the rising air that changes into liquid cloud droplets and ice crystals, which, in turn, grow large enough to fall to Earth as precipitation.

Of lesser importance to weather but of greater importance to sports is the fact that a baseball will "carry" farther in less-dense air. Consequently, without the influence of wind, a ball will travel slightly farther on a hot, humid day than it will on a hot, dry day. So when the sports announcer proclaims that "the air today is heavy because of the high humidity," remember that this statement is not true and, in fact, a 404-foot home run on this humid day might simply be a 400-foot out on a very dry day.

● **FIGURE 1** On this summer afternoon in Maryland, lighter (less-dense) hot, humid air rises and condenses into towering cumulus clouds.

What Happens When Humidity Increases: more water vapor in air!

GAS	Atomic Weight	# Molecules Added or Lost	Atomic Weight Added or Lost
Water moves in (H_2O)	18	10	180 added
Nitrogen (N_2)Leaves	14 x 2 = 28	8 lost	28 X 8 = 224 lost
Oxygen (O_2) Leaves	16 x 2 = 32	2 lost	2 x 32 = 64 lost
Atomic Weight Lost (N_2 and O_2)			**-288**
Atomic Weight Added Water Vapor			**+180**
NET CHANGE	Atomic Weight Of		**-108**

For a given volume of air, higher humidity air (more water vapor) is less dense than less humid air.

Dew Point Spread and Fog

The Dew Point is measured by a special instruments and

The Dew Point Spread = the difference between the air temp and the Dew Point

- The smaller the Dew Point spread – the higher the Relative Humidity.
- When the Dew Point Spread is 0 (the air temp = the Dew Point)
  - the Relative Humidity = 100%
  - Condensation (fog) or deposition typically begins

Condensation and Deposition

- Lower Level Saturation
  - Dew: formed by condensation on solid surfaces cooled below Dew Point (temp. above freezing)
  - Frost: formed by deposition ice crystals on solid surfaces- temp at/below freezing
  - Fog: formed by condensation of water vapor into droplets in air near surface; fog is a “cloud on the ground”
- Upper level Saturation:
  - Clouds: formed by condensation or deposition

Fog- formation of clouds with base at ground level

The types of fog that mainly concern mariners are:

- Radiation Fog
- Advection Fog
- Steam Fog (Sea Smoke)
- Precipitation Fog (Frontal Fog)

Radiation (Ground) Fog

1. On clear nights, with winds less than 5 mph, heat radiates away from the ground, cooling the ground and the air next to it.
2. Heavier, colder air flows into low places.
3. Fog forms as air cools to its dew point; fog is usually less than a couple of hundred feet deep.
4. As sun comes up in morning its heat raises the temperature above the dew point; the fog "burns off."
5. Strong winds prevent fog by mixing cold air near the ground with warmer air higher up.

Radiation (Ground) Fog Photo

Advection Fog - 1

1. Wind pushes warm, humid air inland in the winter - "advection" - refers to air moving horizontally.

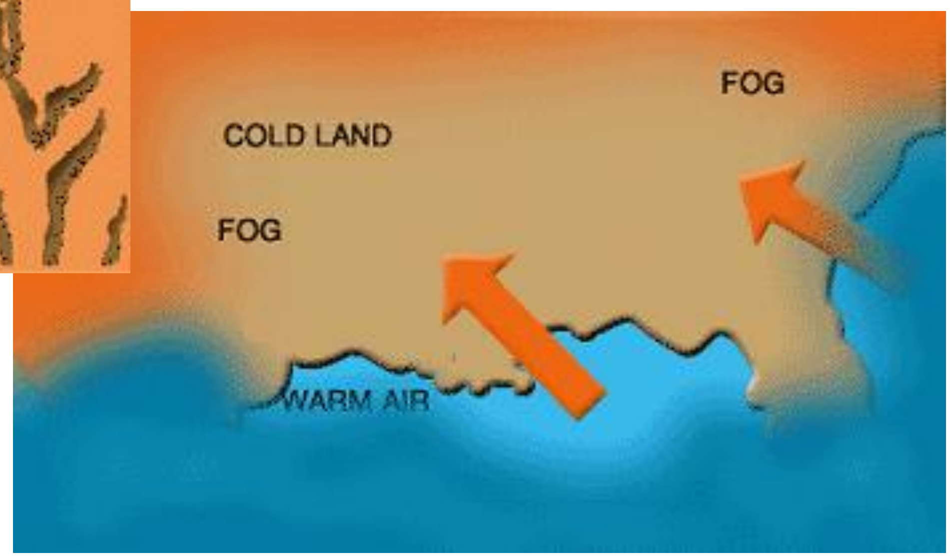
2. As the air blows over cold ground (or colder water - such as a cold current) it cools to the dew point and fog forms.

3. Advection fog can cover wide areas of the central US in the winter, closing airports, or over cold water in the lee of warm air coming from land in the spring.

- Advection fog **accounts for most marine fog**.
- Winds of 5 to 15 knots or so make the fog thicker–but stronger winds will usually "lift" the fog.
- Advection fog disappears when a shift of wind terminates the flow of warm air over the cold surface.
- Examples of advection fog are:
    - The advection of warm moist air from the Pacific Ocean over the cold California Current on the West Coast;
    - The advection of warm moist from the Gulf Stream over cold water off the New England coast; and
    - The advection of **warm moist air from the mid-continent over the cooler Great Lakes.**

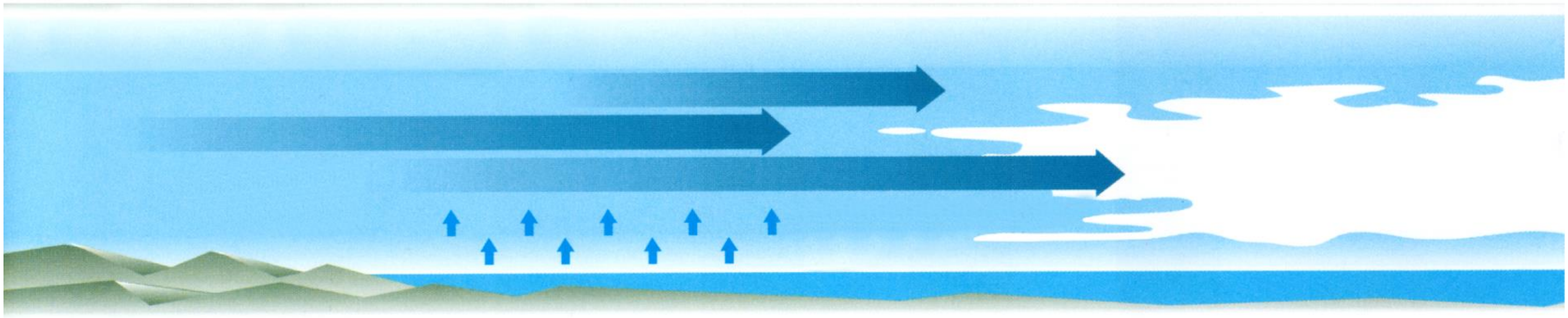
Advection Fog – 2

cold N Pacific Current flows down from Alaska, warm humid air from Pacific flows over cold water --→ FOG



Advection Fog Photo - 1

Steam Fog (Sea Smoke)
cold air moves over warmer water



1. Cold air blows over much warmer water.

2. Water evaporates into the cold air, increasing it to the dew point.

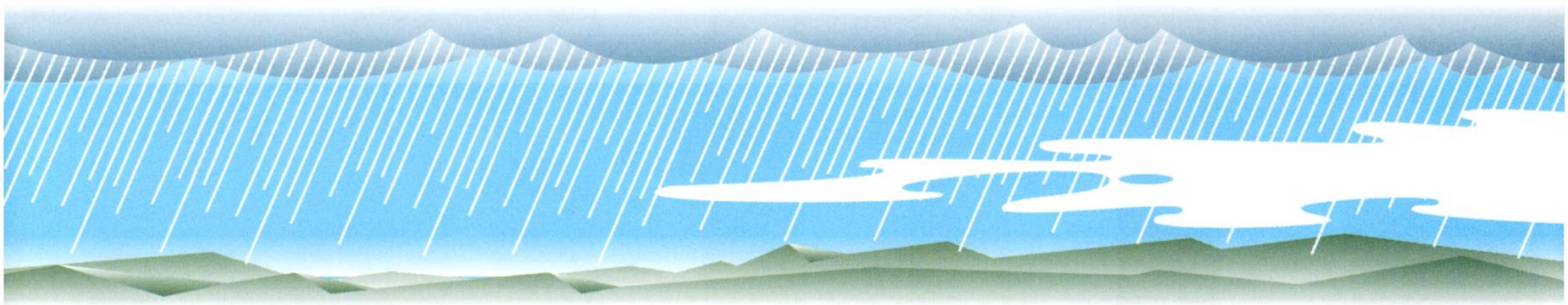
3. Vapor condenses into tiny droplets; on fall days you see "steam" rising from ponds and streams as fog forms a foot or two above the water.

- **Steam fog occurs most frequently over:**
  - **lakes and ponds in the spring and fall; and**
  - **tidal bays, rivers, and open sea during extreme cold spells in the winter.**

Steam Fog Photo

Precipitation Fog

occurs often ahead of a warm front and is referred to as frontal fog.



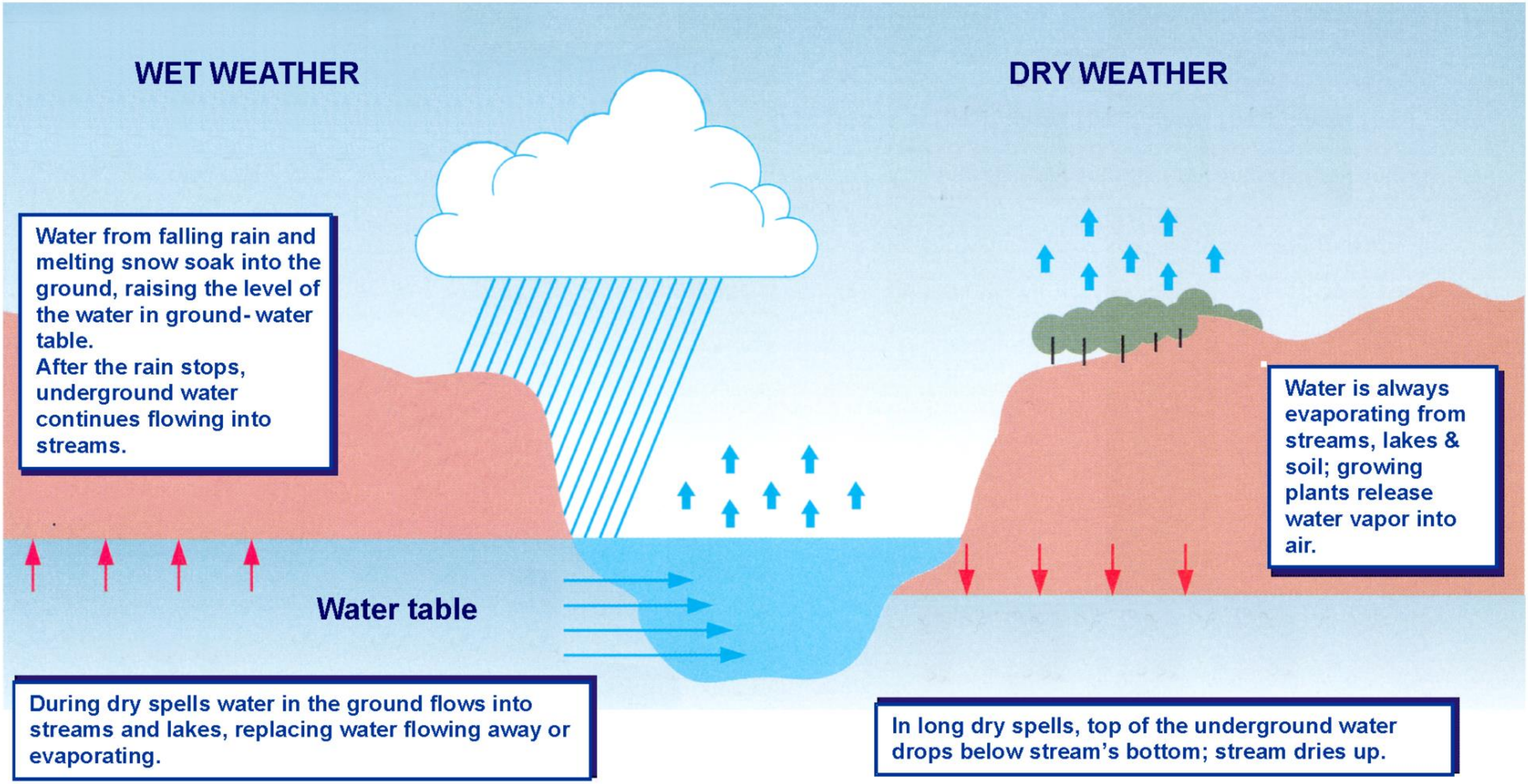
1. Some of the rain falling into cool air evaporates, if the rain is warmer than the air.

2. The added vapor increases the dew point to the air's temperature.

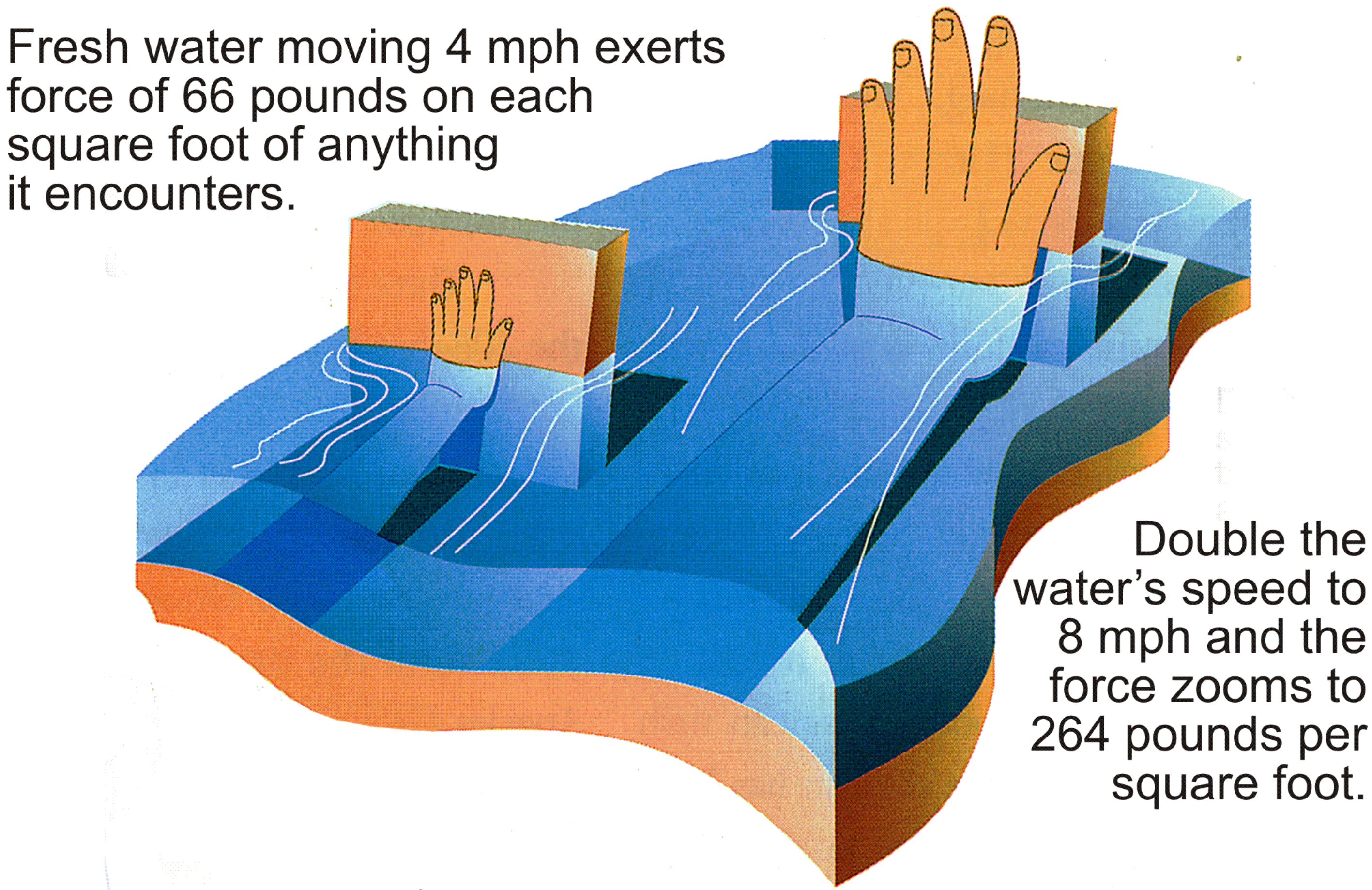
3. Vapor condenses into tiny fog droplets.

Precipitation Fog Photo

How Streams Rise and Fall



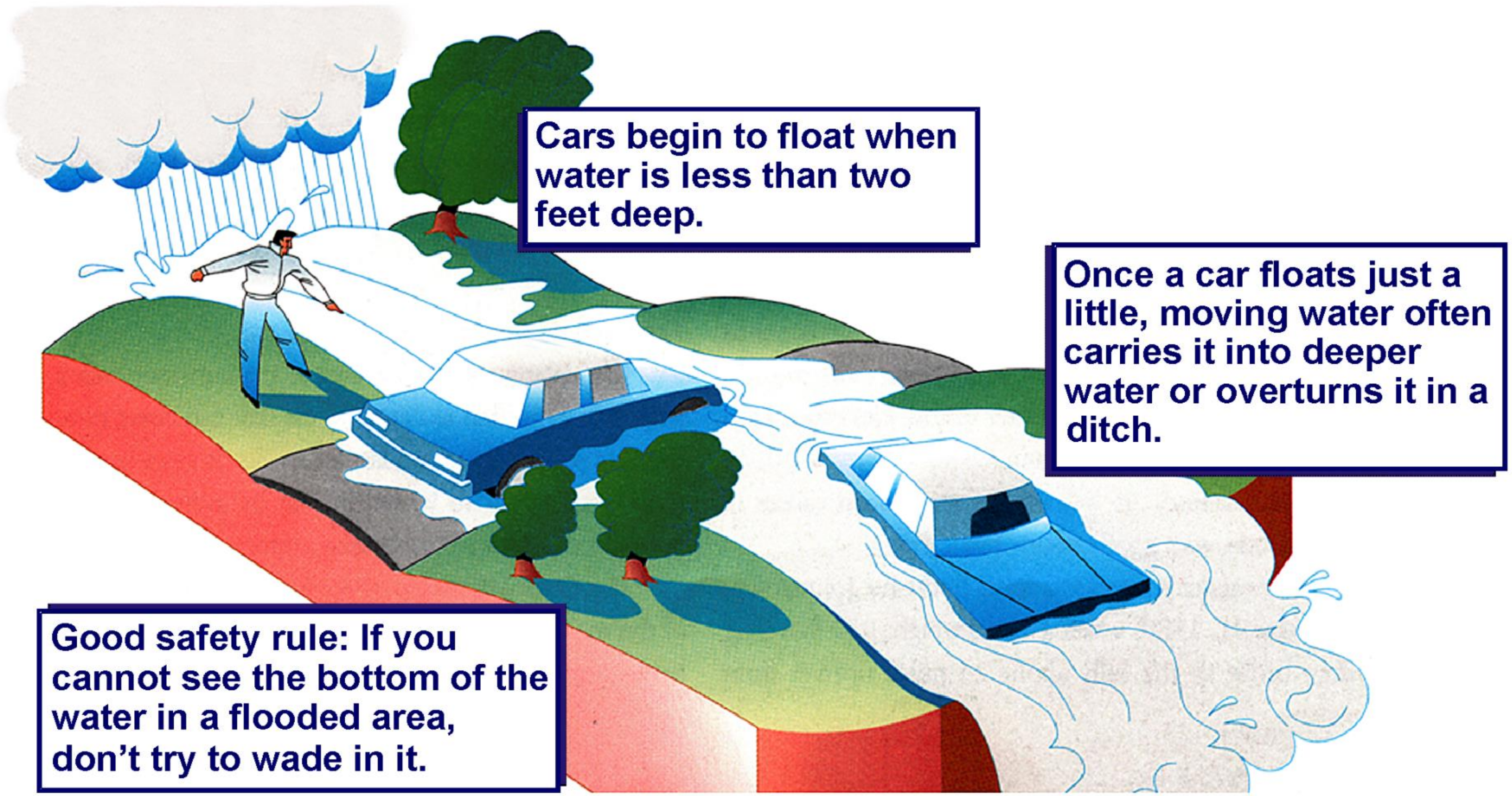
Flood Waters



$F = MA = 1/2\ MV^2$

Thus, doubling the water speed increases the force of water 4 times!

Flood Waters



Chapter 3
Summary

- Ninety-seven percent of the Earth's water is in the ocean.
- The Hydrologic Cycle is the process whereby the Earth's water continuously circulates.
- Water changes its phase (solid, liquid, or gas) by melting, freezing, evaporation, condensation, sublimation and deposition.
- During phase changes water absorbs or releases latent heat.
- Latent heat is stored energy, and when stored in water is a source of energy for thunderstorms.
- Three ways of measuring humidity are mixing ratio, relative humidity and Dew Point.
- When the air temperature equals the Dew Point the relative humidity is 100% and the air is saturated.
- Fog forms when the air is saturated and the temp cools to the Dew Point,
- Fog=clouds with base on ground.
- There are four types of fog: radiation fog, advection fog, steam fog, and precipitation fog.

END OF CHAPTER 3