WATER IN THE ATMOSPHERE

Mixing ratio (w) is the amount of water vapor that is in the air. w is the grams of vapor per kg of dry air. w is an absolute measure of the amount of water vapor in the air.

Saturation - Occurs when RH = 100%. The air is "holding" all the possible water it can at a given temperature. More specifically, the rate of evaporation and condensation are in a dynamic equilibrium and therefore, the vapor content will rise only if the temperature increases. The amount of vapor that would be in the air at saturation is called the **saturation mixing ratio w_s**.

Relative humidity - RH = w/w_S

Example:
T = 0˚C (outside) RH = 100%
T = 20˚C (inside)

What is the indoor relative humidity?

$w_S(0^\circ) = 3.84$ g/kg $w_S(20^\circ) = 15.0$ g/kg

w outside must be 3.84 because the air is saturated; w inside is still 3.84 because no moisture has been added or removed.

Therefore, RH = w/w_S = 3.84/15.0 = 26%

Dew point temperature (T_D)- the temperature to which air must cool ***at constant pressure*** in order for dew to form.

Wet bulb temperature (T_W) - the temperature to which air would cool if water were evaporated into it, since it takes into account evaporative cooling. A raindrop's temperature will be at the wet bulb temperature.

$T_D \leq T_W \leq T$ (where $T_D = T_W = T$ at saturation)

Vapor pressure (e) - part of the total air pressure that is a result of vapor molecules.

Water boils at the temperature for which the saturation vapor pressure (e_s) equals the surrounding air pressure.

Changes of state of water

The change from solid to liquid is called **fusion**, or melting while the change from liquid to water is called **solidification**. (80 calories)

The change from liquid to vapor is called **evaporation**, while the opposite of evaporation is called **condensation.** (600 calories)

Sublimation is the process of changing vapor to a solid or from a solid to vapor, although the change from vapor to solid is sometimes called **deposition.**

Clouds

- There are two types of clouds. **Stratiform** or **stratus** clouds indicate stability. Stratus means layered. **Cumuliform** or **cumulus** clouds are "puffy" and indicate instability.
- The prefix **nimbo**- or the suffix -**nimbus** means precipitating. Precipitating stratiform (**nimbostratus**) clouds produce rain or snow, while precipitating cumuliform (**cumulonimbus**) clouds produce showers.
- The prefix **cirro**- refers to high clouds. **Cirrus** clouds are high, wispy ice clouds.
- The prefix **alto**- refers to mid-level clouds.
- **Stratocumulus** clouds are layered cumulus clouds.
- **Virga** is rain that evaporates before hitting the ground.
- **Mammatus** clouds are pouch-like clouds that are often associated with severe weather.
- Clouds are often used to forecast the weather because they often form because of synoptic-scale conditions.

The Bergeron Process

In order for cloud droplets, which are very small, to become raindrops, they have to increase in mass almost a million times. Indeed, for even a cloud droplet to form, complicated processes must take place allowing for the conversion of water vapor to liquid water. Often times in the atmosphere this process would be virtually impossible without the presence of aerosols. Before we look at this process involving **CCN**, or **cloud condensation nuclei**, let us first examine the case without them, known as **homogeneous nucleation**.

We have said before that the process of the change of state from vapor to liquid is called condensation. Also, this will occur when the relative humidity reaches 100%, or when the vapor pressure equals the saturation vapor pressure. In the microphysics of clouds condensation, however, pure water will condense only when levels of saturation reach upwards of 120% (20% **supersaturation**). The reason is that the spherical shape a water droplet forms is a very unstable structure, hence resisting formation of the droplet. It is not until these high levels of saturation are reached that the forcing will overcome this resistance known as **surface tension**.

The process known as **heterogeneous nucleation** involves "polluting" the pure water with aerosols, or **cloud condensation nuclei** or **CCN**. By adding CCN, water can condense with much lower values of supersaturation, on the order of a few tenths of a percent.

Now that cloud droplets have formed, we will try to understand how they can grow to the size of a raindrop. One such way (although, as we will soon see, not the most important) is through **collision and coalescence**. Cloud droplets will be carried by air currents within the cloud, and if they bump into each other, it is called a collision. However, if they collide *then* stick together, that is called coalescence. Although this process is important, especially in the tropics and in increasing the size of raindrops, it falls short of being the primary mechanism for the formation of raindrops. The process needed was serendipitously discovered by a man named Tor Bergeron while taking a mountain walk.

The **Bergeron process** relies primarily on the fact that **the saturation vapor pressure with respect to ice is less than the saturation vapor pressure with respect to water**. Another important fact is that pure water droplets do not freeze at 0˚C! Again, because of surface tension and the structure of water, to get a pure water droplet to freeze requires a temperature of -40˚C.

Liquid water that is cooler than 0˚C is called **supercooled**. In the atmosphere, similar to CCN, there exist **freezing nuclei**. In contrast to CCN, freezing nuclei are not plentiful in the atmosphere because there structure must be similar to the structure of an ice crystal. Most of the naturally occurring freezing nuclei "activate" at about -10˚C. These freezing nuclei allow for the cloud droplets to freeze around them. Because of the relative sparseness of the freezing nuclei, ice crystals and supercooled water droplets can coexist at the same time. This is where the Bergeron's primary fact becomes important.

The following chart indicates the differences in saturation vapor pressures with respect to liquid water and with respect to ice.

Temperature	RH wrt H_2O(liq)	RH wrt H_2O(ice)
0˚C	100%	100%
-05˚C	100%	105%
-10˚C	100%	110%
-15˚C	100%	115%
-20˚C	100%	121%

Note that since RH= e/e_s, if e_s is made smaller, RH increases.

The air reaches saturation and some of the resulting droplets will come in contact with freezing nuclei (assuming they have reached the activation temperature). We will now have a combination of ice crystals and supercooled water droplets. From the perspective of the supercooled droplets, the air is in equilibrium at saturation, but from the perspective of the ice crystals, the air is supersaturated. Therefore, water vapor will deposit (or sublimate) on the ice crystals. Since the amount of water vapor in the air has decreased, and to the perspective of the supercooled water droplet, the air is subsaturated, the supercooled water will evaporate until the air once again reaches saturation. The process then continues. In a cloud, when temperatures are warmed than -10˚C, almost all of the water is liquid. When temperatures are colder than -40˚C, all of the cloud is ice crystals. It is when the temperature falls in between -10˚C and -40˚C that both liquid and frozen water exist. The Bergeron process results in growth of the ice crystals by deposition (or sublimation) at the expense of the supercooled water droplets.

Atmospheric Instability

- An **adiabatic** process is one in which no external heat is transferred. Remember the Ideal Gas Law is $p=\rho RT$.
- The **parcel** is an imaginary box of air that does not allow a transfer of heat in or out of the box.
- Γ_D = 10˚C/km is the dry adiabatic lapse rate.
- Γ_W = 6˚C/km is our value for the wet adiabatic lapse rate. (The actual rate varies and is dependent on the amount of latent heat released.)
- Γ_E is the environmental lapse rate, which must be measured. On the global average, Γ_E = 6.5˚C/km. Since the atmosphere can do what it wants, therefore it must be measured with a radiosonde.
- **Stability** is when an object is displaced and returns to its original position.
- **Instability** is when an object is displaced and it moves away from its original position.
- **Neutrality** is when an object is displaced and it remains in the new position.
- If $\Gamma_E < \Gamma_W$, then the atmosphere is **absolutely stable**.
- If $\Gamma_E > \Gamma_D$, then the atmosphere is **absolutely unstable**.
- If $\Gamma_W < \Gamma_E < \Gamma_D$, then the atmosphere is **conditionally unstable**.

- Conditional instability means that the air is stable under the condition that the air is not saturated, and unstable if the air is saturated.
- The **LCL** or **lifting condensation level** is the level where lifted air saturates; often where clouds are formed.
- **PBE** is **positive buoyant energy**, which is the same thing as **convective available potential energy** (**CAPE.**)
- **NBE** is **negative buoyant energy**, which is the same thing as **convective inhibition** (**CIN** or **CINH.**)
- The **LFC** or **level of free convection** is the level at which lifted air becomes unstable; found at the intersection of the environmental temperature and the adiabatic temperature, assuming that above that point the air is unstable. The LFC is the beginning of CAPE.
- **EL** or **equilibrium level** is the level at which unstable becomes unstable again. The EL is the end of CAPE.

Understanding The Air Mass Thunderstorm

The air mass thunderstorm is a common and usually non-severe phenomenon that forms away from frontal systems or other synoptic-scale disturbances. They are produced where moist and unstable conditions exist in the atmosphere. Although several storm cells can develop, each individual cell lasts from 30 to 60 minutes and has three stages.

Cumulus Stage

☑ - The storm starts with a warm plume of rising air.
☑ - The updraft velocity increases with height.
☑ - **Entrainment** pulls outside air into the cloud.
☑ - Supercooled water droplets are carried far above freezing level.

Mature Stage

☑ - Heaviest rains occur.
☑ - Downdraft is initiated by frictional drag of the raindrops.
☑ - Evaporative cooling leads to negative buoyancy.
☑ - Top of cloud approaches the tropopause and forms the anvil top.

Dissipating Stage

☑ - The downdraft takes over entire cloud.
☑ - The storm deprives itself of supersaturated updraft air.
☑ - Precipitation decreases.
☑ - The cloud evaporates.

Air mass thunderstorms rarely produce destructive winds or hail because of the absence of vertical wind shear. Vertical wind shear is the change of velocity with respect to height.