

## 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 vapor it can 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?*

$w_s(0^\circ) = 3.84 \text{ g/kg}$      $w_s(20^\circ) = 15.0 \text{ g/kg}$

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,  $RH = w/w_s = 3.84/15.0 = 26\%$

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**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 more commonly called **deposition**.

### Types of Frozen Precipitation

- Sleet is frozen raindrops. Sleet occurs when there is a layer of air that is above freezing on top of a sub-freezing layer. Little chunks o' ice.
- Hail is coalesced frozen rain. It occurs only in thunderstorms.

- Freezing rain is liquid water that freezes when it hits the ground. It usually occurs when the temperature is between  $-3^{\circ}\text{C}$  and  $0^{\circ}\text{C}$ .

### Water on The Earth

- 1300 million cubic km total
- 97% is salty
- 36 million  $\text{km}^3$  of water is outside the oceans
- 28 million  $\text{km}^3$  is in glaciers and ice caps
- 220,000  $\text{km}^3$  is in rivers and lakes
- 12,000  $\text{km}^3$  is in the atmosphere
- 8 million  $\text{km}^3$  is in groundwater

### Floods

Floods are not only caused by excessive amounts of rain but by other, sometimes more severe phenomena. Floods can be caused by the blockage of water by a dam or the collapse of an existing dam. Beavers are one of nature's finest dam builders and have been known to alter established ecosystems by flooding areas up-stream of their dams and drying areas down-stream. A sudden removal of this dam can cause water to rush down the river much as it would if a large man-made dam would collapse.

Another more common type of dam is formed in spring when ice breaks-up and flows downstream until it gets blocked. This will further impede the continuing flow of even more ice blocks. Coupled with water from the winter's melting snow, the flood potential is exacerbated. When rivers flood, the time of peak flooding, or in other words, when the river crests, can be calculated by examining the surrounding terrain including the flood plain. The larger the river, the longer the time between the peak rains and the peak flooding.

**Flash floods** are sudden rises in water as a result of heavy rain or some sort of ice jam or dam failure. There is little time between the initiating event and the flood.

### 1 Fog

One of the most unusual weather catastrophes occurred in December of 1952. Over 4,000 deaths were attributed to one of the worst cases of fog and smoke to ever besiege London. The smog from the persistent fog and the smoke from coal-burning stoves asphyxiated thousands of citizens, while hundreds more died as a result of freak accident induced by extremely short visibility, which at times was less than a couple of feet. Although killer fog like that of the Great London Fog is rare indeed, fog is an extremely common occurrence in almost every part of the globe. Nothing more than clouds at ground level, air near the surface can be cooled sufficiently, allowing the air to reach saturation. This layer of fog can be anywhere from a few feet to several thousand feet thick.

- ⇒ *Radiation Fog* - Radiation fog will form when the ground cools radiationally so that the air coming in contact with the surface will cool to its dew point temperature. Usually around 100 m thick.
- ⇒ *Advection Fog* - Formed when warm air is blown over a cold surface so that the is cooled to its dew point. Fog off the coast of California is partially cooled when the air travels across the cool ocean, in addition to picking up more moisture. As the air travels inland it is forced to rise up the mountains and adiabatically cools even more.
- ⇒ *Frontal Fog* - As a warm front appears, continuous rain over a long period of time may saturate the air thus creating frontal fog.

- ⇒ *Upslope Fog* - This type of fog will form when the air near the ground is cool enough so that it will not rise and moist enough that when it moves upslope, can cool to its dew point. This can take place over several hundred kilometers. For instance, in Kansas, if an east wind is blowing, air starting out at 300m ASL on the eastern border will rise and cool adiabatically as it reaches the western border of the state which is 1200m ASL.
- ⇒ *Steam Fog* - (also known as *Arctic Sea Smoke*) This fog, seen commonly in the winter when a person breathes, is usually only a few meters thick. It forms over water or a wet surface when it is warmer than the surrounding air (for instance, over hot pavement in the summer). As the air is warmed and moistened, it then remixes until it reaches saturation above the surface.

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### Example

Consider a box of air with  $T=10^{\circ}\text{C}$ ;  $\text{RH}=90\%$ ;  $w=7.0\text{ g/kg}$  and a second box of equal mass with  $T=-20^{\circ}\text{C}$ ;  $\text{RH}=50\%$ ;  $w=0.4\text{g/kg}$

Mixing the two boxes gives us a box with an average temperature of  $-5^{\circ}\text{C}$  and a mixing ratio of  $3.7\text{g/kg}$  @  $-5^{\circ}\text{C}$ ,  $w_s=2.64\text{g/kg}$

Therefore,  $\text{RH}=\frac{3.696}{2.64} = 140\%$  ! Even though neither parcel of air was saturated, when they were mixed, fog formed. The temperature of the box is actually a little warmer because as they were mixed and water vapor condensed, latent heat was released.

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### Clouds

- There are two main genre 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. A third genre of cloud is called **Cirroform**. **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 their 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 <sub>2</sub> O(liq)	RH wrt H <sub>2</sub> O(ice)
0°C	100%	100%
- 5°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 on (deposition) 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 warmer 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.
- $\Gamma_D = 10^\circ\text{C}/\text{km}$  is the dry adiabatic lapse rate.
- $\Gamma_W = 6^\circ\text{C}/\text{km}$  is our value for the wet adiabatic lapse rate. (The actual rate varies and is dependent on the amount of latent heat released.)
- $\Gamma_E$  is the environmental lapse rate, which must be measured. On the global average,  $\Gamma_E = 6.5^\circ\text{C}/\text{km}$ . 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.