Atmospheric Moisture

Water may exist in a solid, liquid or gaseous phase depending upon temperature and pressure. The terms *evaporation* and *condensation* are used to describe water in transition between the gaseous and liquid phases (a.k.a. states). The terms *freezing* and *melting* are used to describe water in transition between the liquid and solid states. *Sublimation* is a change of phase directly from the solid state to the gaseous state. *Deposition* is a change of phase directly from the gaseous state to the solid state.

A *saturation state* is a state of equilibrium between water molecules in transition between the liquid phase and gaseous phases. The temperatures and pressures at which saturation states occur are of great importance in determining the course of most weather-related phenomena. As we will see, water vapor, while a very small component of the atmosphere (percentage wise), plays a huge role in determining the course of weather and climate.

Winds enhance evaporation by transporting water vapor molecules in the air away from the site where the water is entering the air, preventing the air from becoming saturated at that site. Higher temperatures also enhance evaporation.

Water molecules in the liquid and gaseous states exist in a state of rapid motion, zipping back and forth as a result of their relatively high energy and collisions with other water molecules. In a parcel of water at a given temperature there will be a distribution of energies associated with various water molecules (i.e., not all of the water molecules will possess the same energy). The higher the temperature the higher the mean value of the energy distribution or the higher the average energy of each water molecule. The greater the energy of an individual water molecule the more vigorous its motion. Water molecules at higher energies move around with greater average speeds (rms speeds). Whenever water exists in the liquid state there will be at least a few molecules that have high enough energies to make the transition from the liquid to the vapor state. When the air is warm, however, many water vapor molecules will possess high enough energies to bounce around for only a short period of time before escaping the liquid state. When the air is cooled, however, lower rms speeds allow water molecules to stick to certain objects (known as *condensation nuclei*) after a collision. When water sticks to condensation nuclei in the air liquid cloud droplets begin to form. Condensation is more likely when the air is cooled both because water vapor molecules can "stick" to condensation nuclei, and because lower rms speeds allow more water vapor molecules to return to the liquid state.

Circulation of Water in the Atmosphere

The transfer of water between land, ocean and atmosphere is accomplished by a number of natural processes. Evaporation places water into the atmosphere. *Transpiration,* the transfer of water into the atmosphere by biological systems (primarily plants), also places water into the atmosphere. Evaporation and transpiration work together in continental areas and account for roughly 15% of the total amount of water placed into the atmosphere. The other 85% comes directly from the oceans via evaporation.

Humidity

The amount of water vapor in the air is referred to as *humidity*. Humidity may be usefully defined in any of several ways.

- *Absolute humidity* is equal to the mass of water vapor divided by the total volume of air, or water vapor density. Absolute humidity changes as the volume of an air parcel changes. Changes in the volume of an air parcel occur normally as air rises or sinks.

- *Specific humidity* is equal to the mass of water vapor in the air divided by the *total* mass of the air parcel (including the water vapor). Since this is a unitless number, it is expressed as a percentage.

- The *mixing ratio* is the mass of the water vapor divided by the mass of the air parcel without the mass of the water vapor included (dry air). Again this is a unitless quantity that is expressed as a percentage.

Specific humidity and mixing ratio remain constant as long as water vapor is not added to or removed from a parcel of air.

Specific humidity is at a maximum in the Tropics and declines as one moves poleward reaching minimum values in each polar region. This implies that the air in the most "arid" desert regions of the planet (30 degrees N or S latitude) actually contains more water vapor than temperate regions much farther north, and certainly more than the Polar Regions.

Vapor Pressure is the pressure exerted by water vapor molecules in the air on surrounding water molecules. In a mixture of gasses, the pressure of an individual gas is proportional to its percentage in the mixture (known as its *partial pressure*). The partial pressure of water vapor in a parcel of air is known as the *actual vapor pressure*. Normally this is a small fraction of the total air pressure. More air molecules generally results in greater air pressure. Actual vapor pressure is a good measure of the total amount of water vapor in the air. As noted previously air is saturated when there is a balance between water molecules leaving and entering the gaseous state. *Saturation vapor pressure* is a measure of how much water vapor is required to make the air saturated at a given temperature or the pressure that the water vapor molecules would exert if the air were saturated at a given temperature.

Relative humidity is another description of the water vapor content of air and may be stated in several different ways:

- *Relative humidity* = water vapor content/water vapor capacity
- *Relative humidity* = actual vapor pressure/saturation vapor pressure x 100%
- *Relative humidity* = actual mixing ratio/saturation mixing ratio x 100%

Stated simply, relative humidity is the ratio of the amount of water vapor in the air to the amount required for saturation at a given temperature and pressure. A relative humidity of 100% means that an air parcel is completely saturated. It is important to note that it is entirely possible to have relative humidity's > 100%. It is, in fact, necessary for relative humidity to exceed 100% for certain meteorological processes to occur.

Although adding or removing water vapor from the air will bring about changes in relative humidity, this is not the only way that such changes can occur. A change in temperature of the air can also change the relative humidity.

Dew Point is the temperature to which a parcel of air must be cooled, at constant pressure and water vapor content, for saturation to occur. Dew point is determined with respect to a flat surface of water. The corresponding *frost point* is determined with respect to a flat surface of ice. Dew point is a very useful indicator of the air's actual water vapor content. High dew points correspond to high water vapor content. When air temperature and dew point are far apart relative humidity is low. When air temperature and dew point are close together relative humidity is high. Relative humidity = 100% when they are the same.

Comparing Humidity

In the Polar Regions, temperatures are low, dew point temperatures are also low, and relative humidity is high. The air in Polar Regions is usually around 80% saturated. Even though the water vapor content of the air is low, the water vapor capacity is low as well. Saturation occurs in air that holds very little water vapor even when the air is relatively dry. As a consequence, the *relative humidity* is higher at Polar Regions than at 30^{o} latitude, while the *specific humidity* is higher at 30^{o} than at Polar Regions.

Not all regions of the earth around 30^{o} latitude are desert. As one traverses 30^{0} of latitude across the continental United States, one notices a distinct difference between the climate of Arizona and that of Alabama. The air masses that prevail over the western deserts of the U.S. come from the Pacific Ocean. The Pacific Ocean is normally very cool. Air over the Pacific is also cool. As westerly winds move this air over land, its temperature increases but its water vapor content does not. Hence the air over the western deserts has a high temperature but a low dew point and very low relative humidity. The Gulf of Mexico, on the other hand, is quite a bit warmer as is the air over it. When this air moves over the southeastern U.S. it warms only a little while maintaining the same water vapor content. The air and dew point temperatures are very close and the relative humidity is consequently quite high. This is why the southwest U.S. is normally hot and dry while the southeast is hot and muggy.