HUMIDITY

Humidity refers to the amount of water vapor in the air. The reference is strictly to water vapor. It does not refer to how much liquid water is in the air or to how much solid water (ice) is in the air. Only the water vapor is referenced by the term, humidity.

There are a large number of different ways in which to view humidity. These include:

ABSOLUTE HUMIDITY
DEW POINT
MIXING RATIO
NUMBER DENSITY
RELATIVE HUMIDITY
SPECIFIC HUMIDITY
VAPOR PRESSURE

Each of these expressions is useful under certain circumstances. Your choice of measurement will depend upon what you intend to do with the results once you have them. Let's take a closer look at each of these ways of looking at humidity.

Absolute Humidity – Absolute humidity measures the mass of water vapor per unit volume of humid air. It may be expressed as:

$$\textbf{Absolute Humidity} = \frac{\underset{\sim}{\textbf{\textit{M}}}}{\textbf{\textit{V}}} \qquad\qquad \text{HUM01}$$

Here, $\underset{\sim}{M}$ is the total mass of water vapor in units of mass and V is the total volume of humid air in units of volume.

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Except in the laboratory, where the volume can be controlled, absolute humidity is not a useful measurement. It varies significantly with variations in temperature and pressure. This is not a problem in the laboratory, where the temperature and the pressure can each be controlled. It is a problem in the free atmosphere where both the temperature and the pressure of a mass of humid air can and do vary independently of one another.

Dew Point or Frost Point – The dew point is a temperature. It is the temperature at which the actual vapor pressure is equal to some published or calculated equilibrium vapor pressure. There is no simple formula for dew point, although numerous approximations exist. This is because there is no simple formula for the equilibrium vapor pressure, and the dew point is a function of that latter property.

The theory is that if a mass of humid air with a specified vapor pressure is cooled, condensation will start when the temperature reaches the dew point temperature. At that point, either dew (at temperatures higher than 0°C) or frost (at temperatures lower than 0°) will form on exposed surfaces. Thus, dew point is used to predict both condensation in cooling air and evaporation in warming air.

Unfortunately, the reality often falls short of the theory. This is because values for equilibrium vapor pressure almost always ignore the fact that the nature and abundance of condensation nuclei in the air strongly affect the true (as opposed to the theoretical) dew point. They also ignore the fact that cooling alone is not usually sufficient to bring about condensation in the free atmosphere.

In air that has many hygroscopic condensation nuclei, condensation will start at a temperature many degrees above the theoretical dew point. This elevated temperature is the true dew point. In air that has few condensation nuclei, condensation will not start until that air is many degrees below the theoretical dew point. This depressed temperature is also the true dew point. In the free atmosphere, condensation rarely ever starts exactly at the temperature corresponding to the theoretical dew point. Instead, it starts at the true dew point. Unfortunately this true dew point is rarely found in published tables.

This is because the equilibrium vapor pressures found in published tables is derived from carefully controlled laboratory procedures, using the condensation of pure water vapor upon a surface of pure water. The true equilibrium vapor pressure over such common condensation nuclei as sea salt, sulfates, strongly ionized particles and other hygroscopic nuclei is different than that found in the

standard tables. It is usually significantly higher, and varies with variations in the hygroscopic force.

Finally, in the absence of condensation nuclei, humid air must often be cooled to relative humidities of as much as 400% before condensation actually occurs—regardless of either the true or the theoretical dew point.

Some scholars have tried to use dew point as a measure of "sensible" humidity—that is, the humidity that we feel. The hypothesis is that high dew points feel humid while low dew points feel dry. Although this works (after a fashion) in specific localities, the concept is ludicrous when viewed from the global perspective.

Cold climates, with temperatures hovering around 0°C, can and do feel excruciatingly damp and raw—even with the dew point in the same low temperature range. Hot climates, with dew points ten to twenty degrees higher than this, can and often do feel quite arid. Dew point combined with ambient temperature is a useful index of sensible humidity. Dew point alone is not.

Mixing Ratio – The mixing ratio is the ratio of the mass of water vapor in a volume of humid air to the mass of dry air in that same volume. It may be expressed as:

$$\textbf{Mixing Ratio } = \frac{\utilde{M}}{\left(M - \utilde{M}\right)} \qquad \text{HUM02}$$

Here, $\utilde{M}$ is the total mass of water vapor in a parcel of humid air and M is the total mass of that parcel, including both humid air and dry air.

The mixing ratio is a very useful concept. Unless either vaporization or condensation takes place, the pressure or the temperature (or both) of a mass of air may be changed significantly without any change in the mixing ratio. Consequently, the mixing ratio is used to track air masses as they move across the face of the globe.

The mixing ratio is similar to the specific humidity and is often used interchangeably with that property.

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Number Density – Number density measures the number of water vapor molecules per unit volume of humid air. It is an essential parameter in kinetic gas theory and statistical mechanics. It may be evaluated by:

$$\underset{\sim}{n} = \frac{\underset{\sim}{p}}{k_B T} = \frac{\underset{\sim}{p}}{\hat{\underset{\sim}{m}}\sigma^2} \qquad \text{HUM03}$$

Here, $\underset{\sim}{n}$ is the number of vapor molecules per unit volume, $\underset{\sim}{p}$ is the ambient vapor pressure, k_B is Boltzmann's constant, T is the ambient temperature, $\hat{\underset{\sim}{m}}$ is the effective mass of the vapor molecule, and σ^2 is the mean square of the molecular velocities along any single axis (or any combination of axes).

Water vapor selectively absorbs, transmits, and scatters both solar and terrestrial radiation. The number density of vapor molecules helps to determine how much of this radiation is absorbed, how much is transmitted, and how much is scattered.

If you could ascertain the mean molecular mass of the vapor molecules present in a mass of humid air, you could say with some justice that number density was analogous to absolute humidity. However, since vapor molecules are found as eighteen different isotopes with twelve different masses; as monomers, dimers, and polymers with an unknown number of masses; and in a wide variety of ions—again with a large and largely unknown number of masses. There is no easy field technique for measuring the mean molecular mass of a parcel of free atmospheric air.

Relative Humidity – Relative humidity measures the actual vapor pressure as a percentage of the theoretical equilibrium vapor pressure at the ambient temperature. It may be expressed as:

$$RH = \frac{\underset{\sim}{p}}{\underset{\sim}{p}^{equilibrium}} \qquad \text{HUM04}$$

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Since relative humidity uses the same theoretical equilibrium vapor pressure as dew point, it is subject to the same sorts of errors.

As air is cooled, the relative humidity increases. This is because the theoretical equilibrium vapor pressure is directly proportional to the temperature. It decreases as the ambient temperature decreases. It thus gets closer to the actual vapor pressure as the air cools. In theory, when the relative humidity reaches 100%, condensation must occur—but not before.

In the free atmosphere, at some times and in some places, condensation occurs at relative humidities as low as 70%; and, at some times and in some places, relative humidities can reach as high as 400% or more without any condensation taking place. Such is the difference between theory and reality.

Nevertheless, relative humidity comes closer than any other measure of humidity to the human body's feeling of "sensible" humidity. We feel the dampness when the relative humidity is high, and we feel the dryness when the relative humidity is low. Consequently, relative humidity is the most commonly used measure of "sensible" humidity—that is, the humidity that we feel.

Specific Humidity – Specific humidity measures the ratio of a mass of water vapor to the mass of humid air that includes it. It may be expressed as:

$$\textbf{Specific Humidity } = \frac{\underset{\sim}{\textbf{\textit{M}}}}{\textbf{\textit{M}}} \qquad\qquad \text{HUM05}$$

Here, both the terms have their previous meanings.

Like the mixing ratio, to which specific humidity is closely related, specific humidity is frequently used to track air masses. Its value doe not change as the air mass changes temperature and density. It does change if either vaporization or condensation takes place in the air mass.

Vapor Pressure – Vapor pressure measures the force transmitted to a surface by the bombardment of vapor molecules upon that surface. It is a function of both the frequency of molecular impact and the impulse transferred with each impact. In still air, it may be expressed as:

$$p = \underset{\sim}{n}_i \underset{\sim}{\varphi} = \left(\underset{\sim}{n}_p \overline{\underset{\sim}{v}}_p \right) \left(2\overline{\underset{\sim}{m}}_i \overline{\underset{\sim}{v}}_i \right) = 2\underset{\sim}{n}_p \overline{\underset{\sim}{m}}_i \sigma^2 = \underset{\sim}{n} k_B T \qquad \text{HUM06}$$

Here, $\underset{\sim}{p}$ is the vapor pressure per unit area, $\underset{\sim}{n}_i$ is the number of molecules that will impact on unit area of surface in unit time, $\underset{\sim}{\varphi}$ is the mean impulse transferred per impact, $\underset{\sim}{n}_p$ is the number of molecules per unit volume having a component of motion toward the sensing surface, $\overline{v}_p$ is the mean molecular velocity toward the sensing surface of the $\underset{\sim}{n}_p$ molecules, $\overline{\underset{\sim}{m}}_i$ is the mean molecular mass of those vapor molecules whose next interaction is with the sensing surface, $\overline{v}_i$ is the mean molecular velocity normal to the surface at the instant of impact (greater than $\overline{v}_p$), σ is the standard deviation of the axial distribution of molecular speeds and also the square root of the mean of the squares of those speeds, $\underset{\sim}{n}$ is the number of vapor molecules per unit volume, k_B is Boltzmann's Constant, and T is the vapor temperature.

In moving air, the value of $\underset{\sim}{n}_i$ in Equation HUM06 changes with the wind velocity. It becomes:

$$\underset{\sim}{n}_i = \frac{\underset{\sim}{n} \overline{\underset{\sim}{v}}_p}{2(\omega + 1)} \qquad \text{HUM07)}$$

Here, ω is the wind velocity parallel to the surface in unit distance per unit time and the other terms have their previous meanings. From this expression it can be seen that ambient vapor pressure drops rapidly with an increase in wind velocity. Consequently, while the number of vapor molecules arriving at a surface (gross condensation) diminishes greatly with wind velocity, the number leaving the surface (gross vaporization) does not change. This results in an increase in net vaporization. This is why winds have significant drying power.

Vapor pressure is sensitive to changes in atmospheric pressure and temperature, as well as to wind velocity. This makes it an excellent laboratory parameter, but a poor one for use in the free atmosphere. Nevertheless, it is probably more widely used than any other measure in climatologic and

meteorological studies. Such is the influence of the experimental scientist over the applied scientist.

Summary – There are many ways to measure humidity in the free atmosphere. Each has its peculiar advantages and disadvantages. Some are best used in the laboratory where you can control the parameters. Some are useful in characterizing portions of the free atmosphere. You should pick the one that best suits your objectives.