prepared by Dr. Andre Lehre, Geology Department, Humboldt State University, Arcata CA
http://www.humboldt.edu/~geology/courses/geology531/531_handouts/water_vapor.pdf

PROPERTIES OF WATER VAPOR IN THE ATMOSPHERE

Heat of vaporization and fusion

In order for liquid water to become water vapor, energy must be added to the molecules of the water sufficient to overcome the inter-molecular attractive forces. This additional heat energy is called the heat of vaporization. This heat energy is absorbed by the water when it evaporates (vaporizes) and is released to the surroundings when the water vapor condenses. In like manner, additional heat must be added to frozen water to break the ice-crystal bonds and cause melting. This is called the heat of fusion. When liquid water freezes, the heat of fusion is released to the surrounding environment.

For water at 0°C (32°F): heat of fusion = 80 cal/gram

For water at 100°C (212°F): heat of vaporization = 540 cal/gram

For water at room temperature: heat of vaporization is approx. 590 cal/gram

Note that heat of vaporization varies with ambient temperature; more heat energy is need to evaporate water at lower temperatures. For temperatures lower than 40°C, the following formula may be used to calculate the heat of vaporization:

$$H_v = 597.3 - 0.564\,T \qquad T = \text{temperature in °C and } T < 40°C \qquad (1)$$

To convert ice to vapor at 0°C takes approximately 677 cal/gram.

Density of Air and Water Vapor

Water vapor has a density (ρ_v) = 0.622 the density of dry air (ρ_{air}), i.e.,

$$\rho_v = 0.622\rho_{air} \quad \text{at the same pressure (P) and temperature (T)} \qquad (2)$$

More generally,

$$\rho_v = 0.622 \frac{e}{R_g T} \qquad (3)$$

T in °K
$R_g = 2.87 \times 10^3$ (gas constant)
e = vapor pressure of water in mb
ρ_v = vapor density in g/cu. cm.

For dry air,

$$\rho_{air} = \frac{P_{dry}}{R_g T} \qquad (4)$$

P_{dry} = pressure of dry air, mb

For moist air,

$$\rho_{air} = \frac{P_a}{R_g T}\left(1 - 0.378 \frac{e}{P_a}\right) \qquad (5)$$

P_a = total pressure of moist air, mb

Vapor Pressure

The pressure exerted by water vapor, independent of the presence of other gases, is called its vapor pressure (e). The vapor pressure of water depends upon temperature alone. In a mixture of gases, the vapor pressure of water is sometimes referred to as its partial pressure. The vapor pressure of water denotes the concentration of water vapor in the mixture of gases.

In a closed container: $e = P - P'$

P = total pressure of mixture
P' = pressure of dry air alone
e = vapor pressure of water

Saturation

The maximum amount of water vapor a space can hold depends on temperature. When this maximum amount is reached, the space is saturated.

saturation vapor pressure (e_s): the vapor pressure existing when a space is saturated; this is the maximum vapor pressure possible at a given temperature. e_s depends on temperature alone.

A formula for calculating e_s is:

$$e_s = 33.8639\,[(0.00738T + 0.8072)^8 - 0.000019\,|1.8T + 48| + 0.001316] \qquad (6)$$

for e_s in mb, T in °C, and $-50°C \leq T \leq +55°C$

If the actual vapor pressure (e) is less than e_s above a water surface, evaporation will occur since water will be vaporizing more rapidly than it is re-condensing.

dewpoint (T_d): the dewpoint is the temperature at which a space containg water vapor becomes saturated with no change in the total amount of water vapor contained (constant water vapor content). In other words, it is the temperature to which we have to cool a parcel of moist air in order to get its water vapor to condense. (i.e., T_d = temperature for which e_s = existing e).
The dewpoint depends on temperature and water vapor content.

A formula for calculating dewpoint is:

$$T_d = T - (14.55 + 0.114T)X - [(2.5 + 0.007T)X]^3 - (15.9 + 0.117T)X^{14} \qquad (7)$$

T = ambient air temperature, °C
X = 1.00 -(f/100)
f = relative humidity at temperature T, %
T_d = dewpoint temperature, °C

specific humidity (q_h): the mass of water vapor per unit mass of moist air

$$q_h = 622\,\frac{e}{P_a - 0.378e} \approx 622\,\frac{e}{P_a} \qquad (8)$$

P_a = air pressure, mb
q_h = specific humidity, gm water/ kg air

relative humidity (f): ratio of actual vapor pressure in air (e) to saturation vapor pressure for that air temperature (e_s), expressed as a percent. This is the ratio of the amount of moisture actually present in the air to the maximum amount it could contain.

$$f\ (\%) = 100\,\frac{e}{e_s} \approx \left(\frac{112 - 0.1T + T_d}{112 + 0.9T}\right)^8 \qquad (9)$$

maximum precipitable water (W_p): total amount of water vapor in a column of air of specified height.

$$W_p = \Sigma\, 0.01\, \overline{q_h}\, \Delta P_a \qquad (10)$$

$\overline{q_h}$ = average of specific humidities at top and bottom of height increment, g/kg

W_p is is mm

ΔP_a = change in air pressure over height increment, mb