UNITED STATES MARINE CORPS

LESSON PLAN

ATMOSPHERIC MOISTURE

INTRODUCTION:

1. Gain Attention. What keeps some individuals in an air-conditioned building all day? Is it the outside air temperature or rather how the air feels to someone?

2. Overview. Moiture is the third basic ingredient, next to heat and wind, that determines the weather over the Earth. It not only supplies the water for cloud formation and precipitation, but also is intimately involved with great quantities of energy in the form of latent heat. This period of instruction introduces the fundamental concepts and significance that atmospheric moisture plays within the environment.

3. Introduce Learning Objectives.

   a. Terminal Learning Objectives. Without the aid of references, but in accordance with the instruction, the student shall successfully state the relationship between atmospheric moisture and humidity.

   b. Enabling Learning Objectives. Without the aid of references, the student shall,

      (1) Define and discuss the following atmospheric moistures variables: dry air, moist air (water vapor), dew point, dew-point depression, humidity types, and vapor pressure.

      (2) State the relationship between vapor pressure and saturation.

      (3) State the relationship between humidity and temperature.

4. Method/Media. This period of instruction will be taught using the lecture method with the aid of QMMCBT-001 "Introduction to the Dynamics of the Atmosphere".

5. Evaluation. You will be evaluated by physically determining the water vapor content in the atmosphere and explain how a change in the current content can affect future weather.

TRANSITION. Current and forecasted amounts of water in the atmosphere play a vital role in daily weather. The next section introduces atmospheric moisture variables and associations with an introduction to their respective roles they play in the atmosphere.

BODY:

1. Variables of Atmospheric Moisture.

a. Dry air. "Dry Air" is defined as a parcel of air with absolutely no traces of water vapor content (0% relative humidity).

b. Moist Air (Water Vapor). Water Vapor is a colorless, odorless, tasteless, and invisible gas varying from as little as .1 of a percent up to 4% in volume within the atmosphere. Even though it only constitutes a small fraction of atmospheric composition, the importance of water vapor is far greater than any other gas present when it comes to understanding atmospheric processes.

(1) Water Vapor is essentially restricted to the lower troposphere. More than half of all water vapor is found within the first mile (1.6 kilometers) of the Earth's surface, while only a fraction exists above 4 miles (6.4 kilometers).

(2) The variable distribution of water vapor within the atmosphere reflects the ease with which it can change from one state to another (recall the water phase changes in QMMPH1-013) at different locations with different pressures and temperatures.

(3) There is a continuous interchange of moisture between the surface of the Earth and the atmosphere, when moisture leaves the surface as a gas and returns in the liquid state. The never-ending process is known as the *hydrologic cycle* (figure 1). This cycle's essential feature is that liquid water (primarily from the oceans) evaporates into the air (water vapor), condenses to the liquid or solid states, and returns to the Earth as some sort of precipitation type (rain, snow, sleet…).

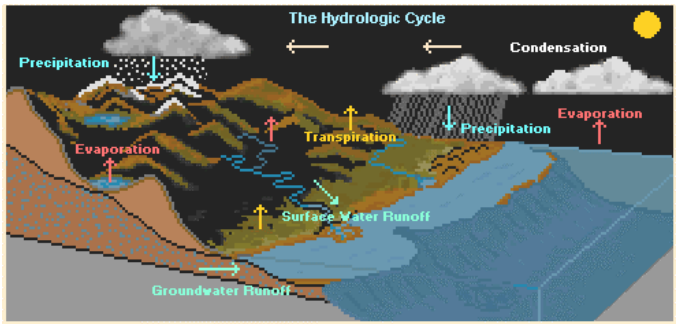

Figure 1 - The Hydrologic Cycle.

c. Humidity. Humidity is a general term that is used to describe the amount of water vapor that is actually present in the air. There are several different types of parameters used to express water vapor content in the air. They are absolute humidity, relative humidity, specific humidity, mixing ratio, and dew point temperature.

(1) Absolute humidity is defined as the mass of water vapor per volume of air. Since air moves around, expands and contracts, absolute humidity is not a constant value and can

change dramatically without the addition or subtraction of moisture.

(2) Specific humidity is considered a more conservative measure and is defined as the mass of water vapor per the mass of air.

(a) The mixing ratio is a closely related value to specific humidity by being defined as the mass of water vapor compared to the mass of dry air.

(b) Since air is always more abundant than water vapor (recall that water vapor is a variable amount from .1 to 4%), these two values can be used to measure available latent heat energy in the air due to its water vapor content, availability of precipitable water, and atmospheric stability.

(3) Relative humidity (RH) is more of a meaningful term. Because of the fact that the air at a given time might contain 10 grams of water vapor per kilogram of dry air (mixing ratio) holds little meaning to the common person. Relative humidity describes how close the air is to *saturation* with water vapor. (Saturation is a state of equilibrium. The amount of water vapor in the air is constant, but water molecules are continuously being evaporated and condensed. In order to maintain a saturated atmosphere, for every molecule of water evaporated, one is condensed at the same time, resulting in no exchange of energy. Recall Conservation of Energy).

(a) Relative humidity is a ratio, expressed as a percentage that compares the actual amount of water vapor that is present to the total amount "capacity" of water vapor the air can hold.

(b) The capacity is the total amount of water vapor that can be in the air at a given temperature. Cold air has a low water vapor capacity, while warm air has a higher water vapor capacity. For example, when comparing the temperatures of 40°F and 80°F, the 80° temperature has the ability to contain twice as much water vapor as the 40° temperature. (INSTRUCTOR NOTE: QMMPH1-017 Moisture Measurements provides an in depth explanation of the various moisture measurements and calculations)

(4) Mixing Ratio (*W*). Most meteorologists prefer to express the water vapor content in the air in terms of the *mixing ratio*.

(a) Mixing ratio is defined as the mass of water vapor in a unit of air compared to the remaining mass of dry air. It is measured in units of mass (grams per kilogram) because the mixing ratio is not affected by changes in temperature or pressure.

(b) Neither the mixing ratio nor absolute humidity can be easily determined by direct sampling. This is why other methods are used to determine and express moisture content in the air. Relative humidity (previously discussed), dew point and vapor pressure serve as some examples of alternative methods.

(5) Saturation Mixing Ratio (W_S). *Saturation mixing ratio is* the theoretical maximum amount of water vapor that air at a specific temperature and pressure can hold. When air is saturated, it cannot hold any additional water vapor.

(6) Dew Point Temperature. The dew point is the temperature at which a parcel of air needs to be cooled to in order for saturation to occur. This occurs at a constant pressure without a change in moisture content.

(a) The dew point temperature is the most widely used measures as is commonly seen on surface chart analysis or television broadcast stations. One may see a temperature of 80°F with a dew point of 70°F. 70° would be the temperature that the air would need to cool to in order for air to become saturated. If the air parcel were further cooled (below 70°), the air temperature would exceed the parcel's saturation mixing ratio and the excess water vapor would condense, typically as dew, fog, or clouds.

(b) If the pressure changed a uniform cooling would not occur. The air temperature would change due to the pressure changes. Dew point relies only on the amount of water vapor in the air. If the temperature is the same as the dew point, saturation occurs and the relative humidity is 100%.

(c) The dew point temperature is an actual measure of moisture currently present in the environment, unlike relative humidity, which is a measure of how close the air is to saturation.

(7) Vapor Pressure. Another way to measure the moisture content of the air is obtained from the pressure that is exerted by the water vapor.

(a) Imagine a closed container (figure 2) that is half full of pure water and dry air is located on top of the water. Immediately, some of the water molecules will leave the water and begin to evaporate into the dry air. This addition of water vapor into the air can be detected by a small change in pressure. The increase in pressure is caused by the motion of the water vapor molecules that were added to the dry air through evaporation. This pressure is defined as *vapor pressure*.

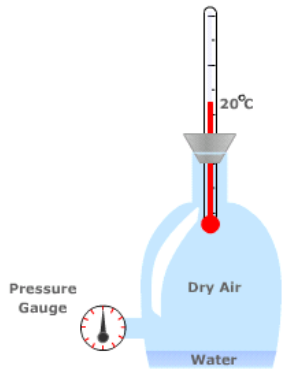

Figure 2 – Initial Conditions of dry air at 20°C
with no observable vapor pressure.

(b) Vapor Pressure is technically defined as that part of the total atmospheric pressure attributable to its water vapor content. For further reading, one may study *Dalton's Law of Partial Pressures*.

(c) Saturation Vapor Pressure.

(1) Referring back to the closed container (figure 3) example stated above, initially, more and more molecules will leave the water surface (evaporate) than will return to the water (condense). However, as more and more molecules of water are evaporating, the vapor pressure in the air of the container is steadily increasing causing more and more water vapor molecules to return as liquid molecules.

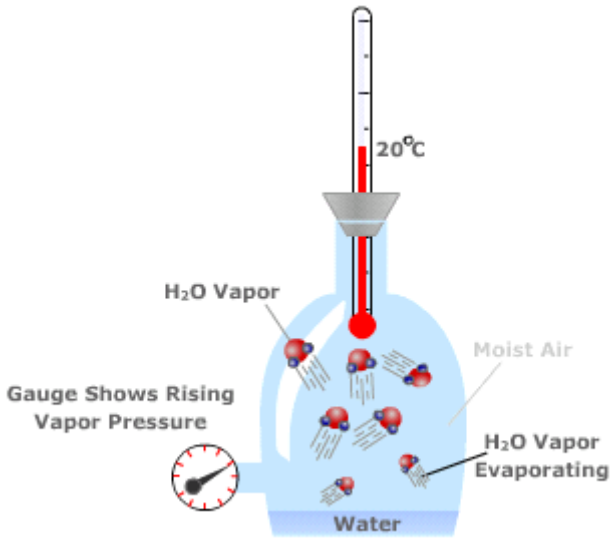

Figure 3 – Evaporation generates measurable vapor pressure.

(2) A balance will eventually be reached (figure 4), in which the number of water molecules returning to the surface equal the number leaving (this is the point of saturation).

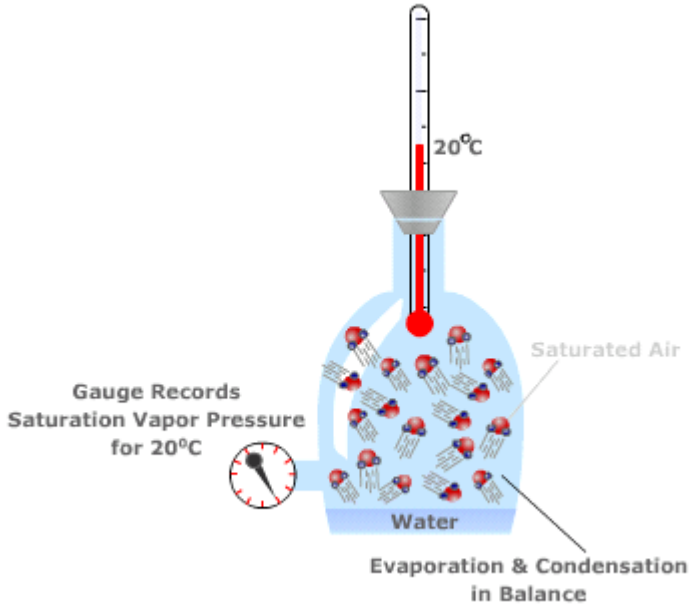

Figure 4 – Increasing molecules escape from water surface, the steadily increasing vapor pressure forces an increasing number of molecules to return to the liquid. Eventually, the number of molecules leaving the water surface balances the number of molecules returning to the surface.

(3) When air has reached the point of saturation, the pressure exerted by the motion of the water vapor molecules is termed *saturation vapor pressure*.

(4) If we add heat to the closed container (figure 5) to disrupt the equilibrium of saturation, this added energy would increase the rate at which the water molecules will evaporate from the surface.

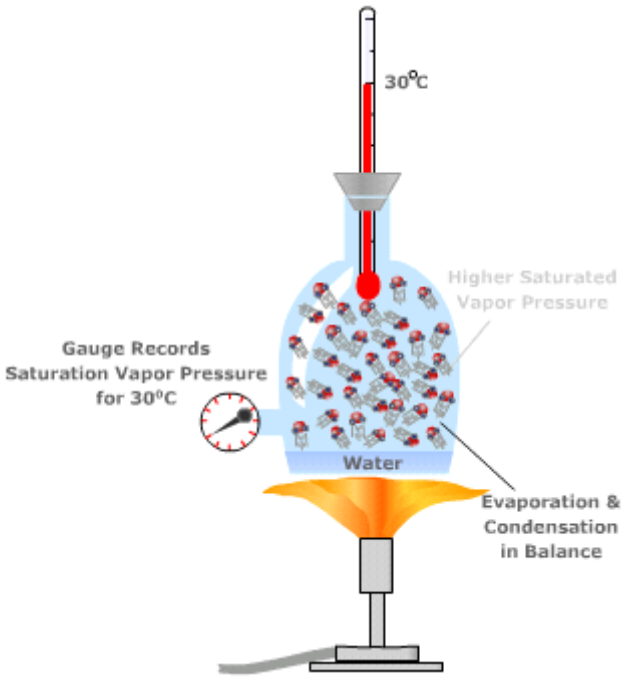

Figure 5 – The rate of evaporation increases with an increase in temperature causing the vapor pressure to increase until a new balance is reached.

(5) Now, the vapor pressure in the "dry air" will increase to once again achieve that state of equilibrium, or saturation, of evaporation and condensation.

(6) This example proves the important concept that saturation vapor pressure is temperature dependent. At higher temperatures it take more water vapor to saturate the air.

(7) For every 10°C (18°F) increase in temperature, the amount of water vapor that is required for saturation is almost doubled. Roughly four (4) times as much water vapor is need to saturate the air at 30°C (86°F) than at 10°C (50°F).

TRANSITION. Understanding the variables associated with atmospheric moisture is of primary concern. Without this knowledge, understanding the relationship moisture has with temperature causing evaporation and condensation would become cloudy and difficult to interpolate.

2. Moisture Associations and Relationships.

a. Water Vapor and Temperature. The atmosphere behaves the same way our closed container had behaved; only gravity acts as the lid on the atmosphere. Molecules are trying to forever maintain a balance of evaporation and condensation. However, a balance cannot always be achieved.

(1) Temperature of the surface water is one of the major factors that determine whether the rate of evaporation will exceed the rate of condensation, or vice versa.

(2) This in turn determines how much motion, or kinetic energy, the water molecules have. At higher temperatures, the molecules have more energy and can more readily escape. Otherwise stated, hot water has more energy, therefore it will evaporate faster than cold water.

(3) Table 1 demonstrates the relationship between temperature and saturation vapor pressure, *the pressure that would be exerted by just the water molecules in vapor phase in the air if the air were saturated.*

°C	hPa	°C	hPa	°C	hPa	°C	hPa	°C	hPa	°C	hPa	°C	hPa
-30.0	0.51	-20.0	1.25	-10.0	2.86	0.0	6.10	10.0	12.26	20.0	23.36	30.0	42.40
-29.0	0.56	-19.0	1.37	-9.0	3.09	1.0	6.56	11.0	13.11	21.0	24.84	31.0	44.90
-28.0	0.61	-18.0	1.49	-8.0	3.35	2.0	7.05	12.0	14.01	22.0	26.41	32.0	47.52
-27.0	0.67	-17.0	1.62	-7.0	3.61	3.0	7.57	13.0	14.96	23.0	28.07	33.0	50.28
-26.0	0.74	-16.0	1.76	-6.0	3.90	4.0	8.12	14.0	26.0	24.0	29.81	34.0	53.17
-25.0	0.81	-15.0	1.91	-5.0	4.21	5.0	8.71	15.0	17.03	25.0	31.65	35.0	56.20
-24.0	0.88	-14.0	2.07	-4.0	4.54	6.0	9.34	16.0	18.16	26.0	33.59	36.0	59.39
-23.0	0.96	-13.0	2.25	-3.0	4.89	7.0	10.01	17.0	19.35	27.0	35.63	37.0	62.73

Table 1. Saturation Vapor Pressure
(To show this graphically, one could plot the data from table 1 on a graph)

b. Vapor Pressure and Temperature. The vapor pressure in the air around the liquid is another major factor in determining if evaporation or condensation will win the war.

(1) In our closed container, or our atmosphere, the vapor pressure determines the rate at which the water molecules will return to the surface (condense).

(2) When the air is dry, lower vapor pressures, the rate at which air molecules return to the liquid state is low.

(3) When the air around a liquid has reached its saturation vapor pressure, the rate of condensation equals the rate of evaporation. There is neither a net condensation nor a net evaporation.

(4) With all else being equal, net evaporation is greater when the air is dry (low vapor pressure) than when the air is humid (high vapor pressure).

c. Changing the Humidity Content. Changes to the relative humidity content can be changed in two (2) ways since it is based on the air's water vapor content and the amount of moisture required for saturation. Humidity is also dependent on temperature.

(1) The Addition or Subtraction of Moisture.

(a) When water vapor is added to a parcel of air, the humidity content increases until saturation occurs (100% relative humidity). What happens if even more water vapor is added after saturation occurs? Relative humidity cannot reach above 100% therefore the excess water vapor will condense to form liquid water.

(b) Water vapor is removed from the atmosphere by the process of condensation when enough water vapor has been added in order for saturation to occur.

(2) Temperature Changes. Humidity is inversely proportional to temperature if moisture content remains constant.

(a) Using the dew point temperature, which is a direct measure of moisture, of 50°F and an air temperature of 60°F, atmospheric conditions are close to saturation at approximately 83% relative humidity.

(b) If the temperature is double to 120°F, without a change in moisture, the humidity content is halved to approximately 42%. If the temperature is dropped down to the dew point temperature, the environment is now saturated at 100%.

(c) There are three (3) major ways that changes in air temperature can have an effect on humidity. They are (1) diurnal temperature changes - daylight versus nighttime temperatures (figure 6), (2) horizontal movement of air from one location to another location (warm or cold air advection), and (3) vertically moving air currents.

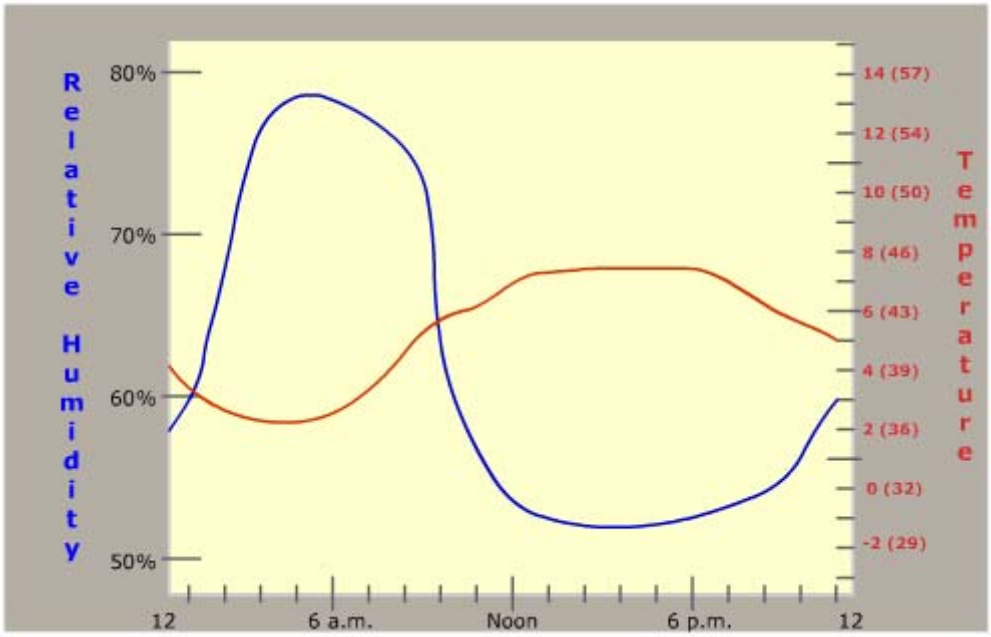

Figure 6 – Example of diurnal temperature and relative humidity curve.

TRANSITION. Changes in moisture content or short/long term temperature changes affect the humidity levels in the atmosphere. These processes affect the occurrence of everyday weather.

OPPORTUNITY FOR QUESTIONS:

1. Questions from the Class. At this time, are there any questions concerning the content you just learned?

2. Questions to the Class.

   a. QUESTION. What is the reasoning of the mixing ratio?

   b. ANSWER. To find the mass of water vapor to the mass of the dry air.

SUMMARY: This period of instruction provided a foundation on the variables associated with atmospheric moisture. It defined and discussed the significance of each variable, as well as, defined several pertinent relationships that take place within the atmosphere.

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