UNITED STATES MARINE CORPS

LESSON PLAN

CLOUD GROWTH

INTRODUCTION:

1. Gain Attention. Rained out baseball games and rained out barbecues. The transition from clear skies to overcast skies and eventual rainfall is often unwanted, but how does the process occur?

2. Overview. During this period of instruction, the student(s) shall be introduced to the processes the initiate and enhance cloud growth.

3. Introduce Learning Objectives.

a. Terminal Learning Objective. Without the aid of references, but in accordance with the instruction, the student(s) shall define and discuss the process that contribute to cloud droplet growth and sustainment.

b. Enabling Learning Objective(s). Without the aid of reference, but in accordance with the instruction, the student(s) shall define and discuss:

(1) Growth of the cloud droplet by condensation and collision and coalescence.

(2) The ice crystal process.

(3) Explain why growth by condensation alone would be a slow process.

4. Method/Media. This period of instruction will be taught using the lecture method with the aid of a Macromedia Flash presentation "QMMPH1-Introduction to the Dynamics of the Atmosphere".

5. Evaluation. The student(s) shall not be evaluated at the conclusion of this period of instruction.

TRANSITION. Initially, cloud growth is rapid. However, it quickly diminishes because the available water vapor is being consumes by the large number of competing droplets. The result is a formation of a cloud consisting of billions of tiny water droplets that are so small that they can remain suspended in the air.

BODY:

1. Growth Processes of Cloud Droplets. Recall that cloud droplets are formed by the attraction of water vapor molecules onto cloud condensation nuclei (CCN), which are hygroscopic. Initially, cloud growth is rapid. However, it quickly diminishes because the available water vapor is being consumes by the large number of competing droplets. The result is a formation of a cloud consisting of billions of tiny water droplets that are so small that they can remain suspended

in the air.

a. Growth by Condensation. There are several factors that govern the growth of cloud droplets by condensation. Ultimately, this type of growth is revolved around the relative humidity. It is the resulting relative humidity that determines if a cloud droplet will grow, shrink, or remain the same size. However, droplet size and salinity also play crucial factors.

(1) Relative Humidity. Relative humidity is the ratio between the vapor pressure (e) to the saturation vapor (e_s) pressure, or RH = e/ e_s. If air is "*saturated*", then it contains 100% relative humidity, the air is holding the maximum amount of water vapor is can possibly hold. By looking at the ratio, this means that the vapor pressure must equal the saturation vapor pressure. When determining if a cloud droplet will grow, it is necessary to compare the saturation vapor pressure of the environment to the saturation vapor pressure of the pure water droplet (comparing humidities).

(a) If the relative humidity is less than 100%, evaporation exceeds condensation and the droplet will shrink (If RH < 100%, then evap > cond. = droplet shrinkage).

(b) If the relative humidity is 100%, evaporation equal condensation and the droplet's size will remain unchanged (If RH = 100%, then evap=cond. = no change in droplet size).

(c) If the relative humidity is greater than 100%, evaporation is less than condensation, and the droplet will grow in size (If RH > 100%, then cond. > evap. = droplet growth).

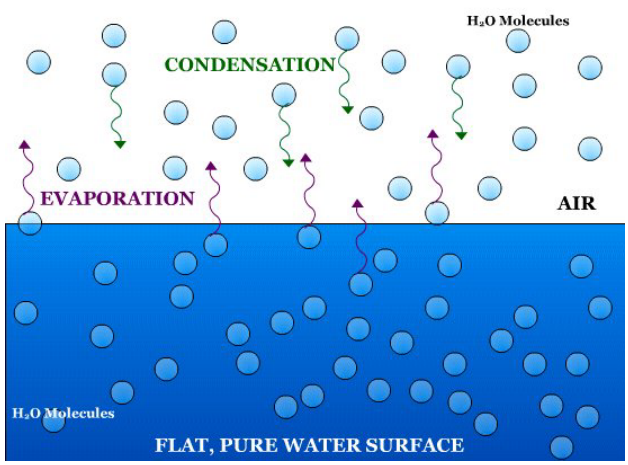

Figure 1 - The air and the water surface are both saturated. Evaporation equals condensation and vapor pressure equals saturation vapor pressure.

If the relative humidity has to be greater than 100% for the cloud droplet to grow, how do they ever grow? Indeed, the process is very slow, there must be additional factors that enhance droplet growth.

(2) Salinity of the Droplet. Water droplets may be pure water, but most contain some amount of CCN. The mix of CCN and pure water in a droplet determines is solution. Note, that the guidelines that were just presented were for pure water only. Each droplet will have a different saturation vapor pressure (humidity) based upon its solution concentration (the amount of CCN and pure water). This is called the *solute effect*.

(a) Droplets containing a higher solution, or more CCN, will have a lower saturation vapor pressure (humidity) than those of more pure droplets.

(b) Droplets containing a lower solution, or less CCN, will have a higher saturation vapor pressure than those of less pure droplets.

(c) If two (2) droplets are the same size but have different purities, than water vapor will evaporate from the more pure droplet (higher pressure) and condense on the less pure droplet (lower pressure). Flow is always from higher to lower pressures.

(d) This results in the more pure droplet shrinking or decreasing in size, while the less pure droplet grows at its expense.

(3) Droplet Curvature. Assuming the surrounding air is saturated, the evaporation rate of a curved surface is greater than the evaporation rate of a flat surface.

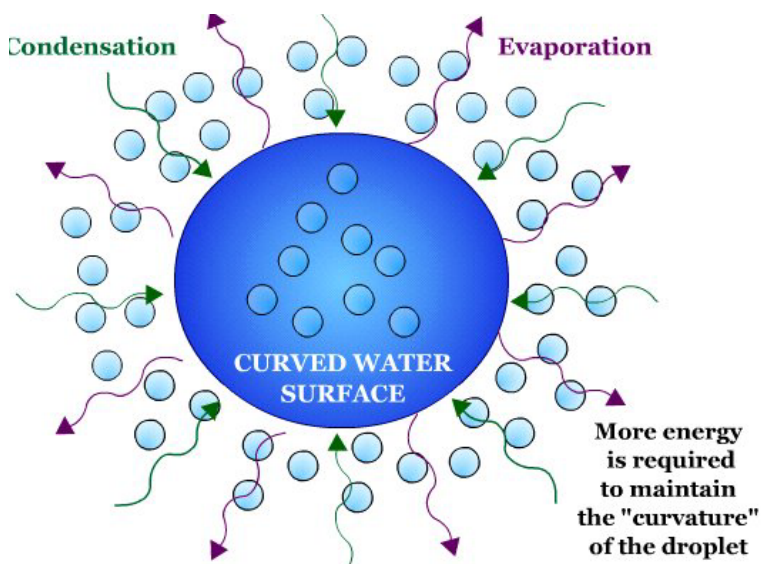

Figure 2 – On a curved water droplet, more energy is required for evaporation that on a flat surfaced droplet.

(a) Smaller droplets have more tightly rounded edges that require the water molecules on the surface of the edge to have more energy because it takes more energy to maintain the *curvature* of the droplet. Smaller droplets will have smaller radii and higher saturation vapor pressures because evaporation exceeds condensation.

(b) Water molecules on the surface of larger droplets have less energy because the radius of a larger droplet is greater, therefore containing less curvature and a lower saturation vapor pressure.

(c) The smaller droplet will shrink by evaporation, while the larger droplet will grow by condensation because the water vapor will be transported from higher to lower saturation pressure, or from the smaller droplet to the larger droplet.

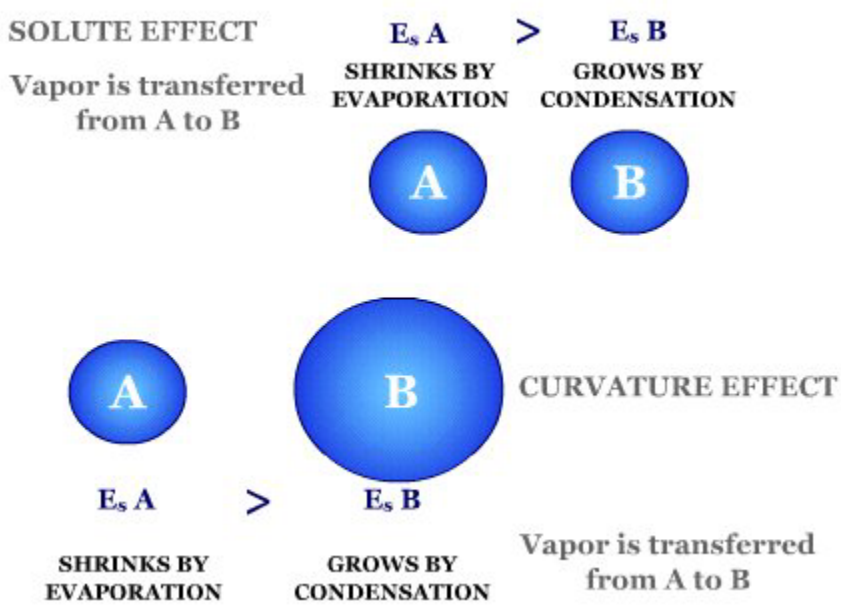

Figure 3 – Solute Effect – water vapor will evaporate from the more pure water droplet. Curvature Effect – Droplets that are smaller and more tightly curved have more vapor, the larger droplet grows at the expense of the smaller one.

(4) Even in extremely moist air, cloud growth by condensation is a slow process and the immense size difference between cloud droplets and rain droplets (it takes approximately one million cloud droplets to form a single rain droplet) suggests that condensation alone cannot be responsible for the formation of cloud droplets or ice crystals large enough to fall to the ground without first evaporating.

b. Collision and Coalescence. When clouds grow in size, an interaction between water droplets occurs and is called collision and coalescence.

(1) As a larger water particles fall, it encounters smaller droplets or ice crystals that are falling at a slower rate. Some of the small particles lying in the path of the larger ones will collide and merge together forming an even larger water droplet. When these water droplets stick together, it is known as coalescence.

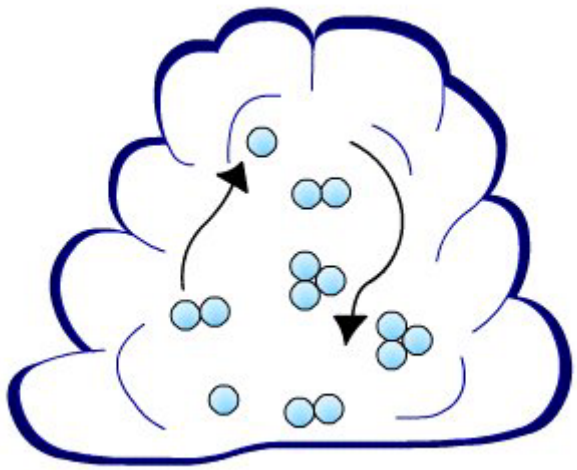

Figure 4 - During the process of collision and coalescence, water vapor molecules are carried throughout the cloud by updrafts and downdrafts. Molecules collide with each other and grow.

(2) Factors influencing the efficiency of the collision and coalescence process include time in cloud and updraft strength. Obviously the longer a water droplet remains in the cloud then the more likely it is to come into contact with other droplets.

(3) The strength of the updrafts within the cloud will determine how much the water droplet will remain circulating through the cloud thus increasing the possibility of collision and coalescence.

2. Growth of Ice Crystals. Most clouds that will produce precipitation in the middle latitudes are mixed; that is they contain both super cooled (liquid water existing below the freezing point) liquid water droplets and ice crystals in the same environment.

a. If the vapor pressure lies between the saturation vapor pressures for ice and the super cooled water droplets are at a temperature below 0°C, then the conditions are supersaturated for the ice crystals and sub saturated for the water droplets simultaneously.

b. This would cause the water droplets to evaporate, reducing their size and putting vapor into the air. This rise in vapor pressure will cause ice crystals to grow by vapor deposition.

c. This process causes ice crystals to get very large in a short period of time. Since there are much fewer ice crystals than super

cooled droplets, there is plenty of water to transfer from droplets to the ice crystals. This allows the ice to get large enough to fall as precipitation within the time constraint of the cloud lifetime.

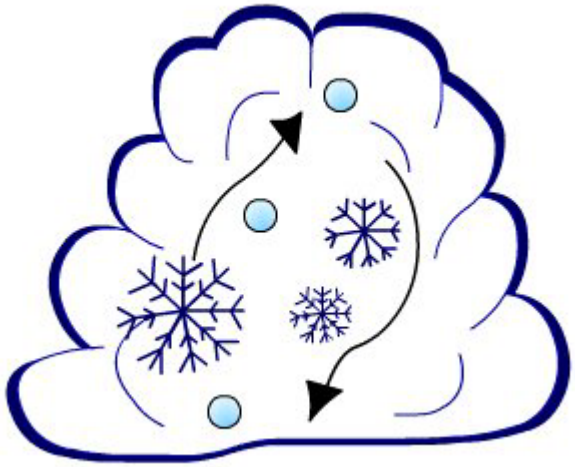

Figure 5 - The ice crystal process.

d. The falling ice crystal will probably fall through the population of super cooled droplets below, accumulate them, and grow into a much larger ice particles.

e. This process where ice crystals grow at the expense of cloud droplets is called the *Ice Crystal Process*. It is also named after the Norwegian researchers who discovered it, Bergeron and Findeisen, and called the Bergeron-Findeisen Process or just Bergeron Process.

OPPORTUNITY FOR QUESTIONS:

1. Questions from the Class. At this time are there any questions pertaining to the information that has just been presented?

2. Questions to the Class. There are no questions for the student(s) at this time.

SUMMARY: During this period of instruction, the student was informed of the various processes that aid to the growth of both cloud droplets and ice crystals. The growth rate of a cloud droplet by condensation proves to be too slow to be the main trigger for cloud growth. Other factor of droplet size and solution content contribute to this process. The student(s) was instructed on the different phases a cloud can go through during its life cycle, specifically convective clouds.

REFERENCE:

The Atmosphere, An Introduction to Meteorology. Frederick K. Lutgens and Edward J. Tarbuck.

Physical Geography, A landscape Appreciation. Tom L. McKnight and Darrel Hess.