UNITED STATES MARINE CORPS

LESSON PLAN

SUN ANGLE

INTRODUCTION:

1. Gain Attention. It's a nice sunny day in Chicago, Illinois with an outside air temperature of 32 degrees. How can it be so cold if the sun is fully shining?

2. Overview. In this topic, the student(s) will learn about the characteristics, properties, and laws that govern the Sun's rays and how they affect the Earth and its atmosphere.

3. Introduce Learning Objectives.

a. Terminal Learning Objective. Without the aid of reference, be able to explain with moderate understanding about radiation and how it affects can be seen.

b. Enabling Learning Objective(s). Without the aid of reference, but in accordance with the instruction,

(1) Describe the Earth's Radiational Budget.

(2) Define the relationship between sun angle and daylight hours.

(3) Discuss the significance of the Greenhouse effect and the impact it has on the Earth.

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

4. Evaluation. You will be evaluated by demonstrating that you understand the basis of the suns radiation.

TRANSITION. The Sun is the only important source of energy for the Earth's atmosphere. Millions of other stars radiate energy, but they are all too far away to impact the Earth. The Sun essentially supplies all the energy that supports life on Earth and energizes most of the atmospheric processes.

BODY:

1. The Radiation Budget. The radiation budget, or balance, of the Earth is an accounting for the incoming and outgoing components of

radiation from the Sun. These components are balanced over long time periods and over the Earth as a whole. If they weren't, the Earth would be continually cooling or warming. However, over a short period of time, radiant energy is unequally distributed over the earth.

INSTRUCTOR NOTE: For the purposes of this instruction, an introduction to Short and Longwave Radiation is given. A detailed discussed on Radiation as a heat transfer mechanism can be found in QMMPH1-013 "Heat & Energy".

a. Electromagnetic Waves. Electromagnetic waves are classified on the basis of wavelength. Wavelengths vary tremendously. Electromagnetic waves of various wavelengths make up the *electromagnetic (em) spectrum*. EM waves posses the ability to transport energy without requiring a medium, or some type of matter, to pass through. These waves travel outward from the Sun at the speed of light (186,000 miles per second) and do not lose any energy as they transverse through space. However, as the distance from the radiating body (the Sun) increases, the EM waves do decrease in intensity. With the distance that the Earth is from the Sun and the fact that the EM waves lose intensity with distance, less than one two-billionth of the total energy emitted from the Sun reaches the Earth. This all happens in approximately just 8 seconds. One two-billionth may not seem like a lot, but when compared to the total amount of solar energy that the Sun produces, the Earth receives an enormous amount. The amount of energy received in 1 second is approximately equal to all the electric energy generated on Earth in one week's time.

b. This period of instruction will only discuss the portions of the spectrum that are relevant to meteorological uses.

(1) Ultraviolet waves are wavelengths that measure from .01 to .4 micrometers. These waves are too short to be seen by the human eye. The Sun is a predominate source of ultraviolet waves. The top of the atmosphere absorbs much of the ultraviolet radiation that is emitted from the Sun, the surface of the Earth receiving little if any ultraviolet radiation.

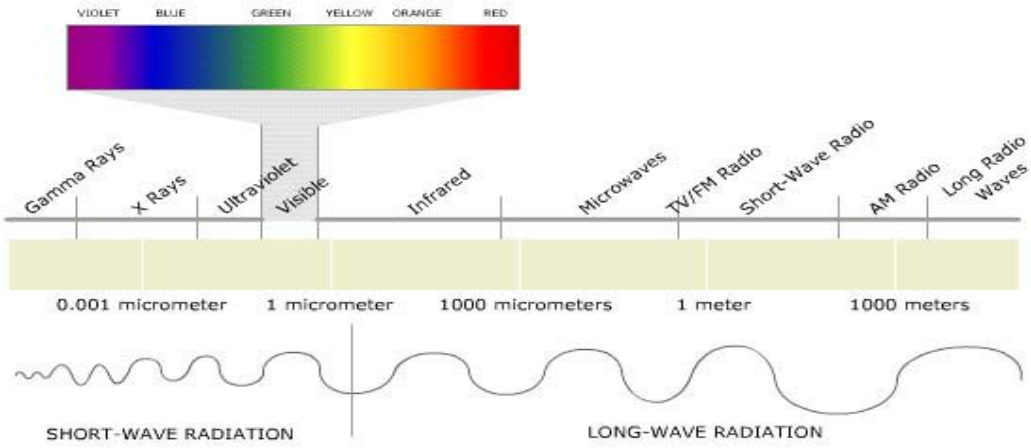

Figure 1 - Electromagnetic Spectrum.

(2) Visible light is concentrated in a very narrow band between .4 and .7 micrometers. A large portion of energy from the Sun comes to the Earth as visible light. However, only about 3% of all electromagnetic energy is contained within the visible-light spectrum.

(3) Infrared waves are located between .7 and 1,000 micrometers. These waves are too long to be seen by the human eye. They are typically emitted by hot objects and are also called heat rays. Infrared waves are used in a variety of ways, and this pertains to their ability to pass through material that would otherwise block light rays. The Earth's radiation is entirely infrared, while only a portion of the Sun's is.

c. Shortwave Radiation. Radiation from the Sun is emitted in the form of shortwaves. These shortwaves fall in the visible portion of the electromagnetic spectrum due to the high frequencies. The amount of solar radiation that reaches the surface of the Earth depends on a number of factors including, latitude, longitude, time of day, and time of year. Various scattering and absorbing constituents in the atmosphere such as water vapor, liquid water, and ozone aerosols also play a factor in the amount of solar radiation that reaches the surface. The radiant solar energy is from nuclear energy and the temperature of the Sun is 6000K (Kelvin). The spectrum of the solar radiation received at the top of the atmosphere is well approximated by the spectrum of a *blackbody* (A blackbody is defined as an object that absorbs all incoming radiation and emits all energy at full efficiency for all wavelengths. The amount of energy emitted by a blackbody can be calculated for different wavelengths having a surface temperature of about 6000K). Therefore, the Sun may be considered as a blackbody.

(1) Stefan-Boltzmann Law. The Stefan-Boltzmann Law states that objects that have a very high temperature emit energy at a greater rate or intensity than objects at a lower temperature. So as a temperature of an object increases, more total radiation is emitted each second. This is expressed

mathematically as ($E \sim T^4$). Where E is the maximum rate of radiation emitted by each square centimeter of surface area of the object and T is the object's surface temperature in degrees Kelvin. This states that objects with temperatures above absolute zero (0 K or $-273^{o}C$) emit radiation at a rate proportional to the fourth power of their absolute temperature.

(2) Wien's Law. The *Wien's law* or *Wien's displacement law* in physics states that there is an inverse relationship between the wavelength of the peak of the emission of a blackbody and its temperature.

$$\lambda_{\mathrm{max}} = \frac{0.002898}{T}$$

where T is the temperature of the blackbody in kelvin (K) and λ_{max} is the peak wavelength in meters.

(a) Simply stated, the hotter an object is, the shorter the wavelength at which it will emit radiation. For example, the surface temperature of the sun is 5780 K, giving a peak at 500 nm. As can be seen in the article Color, this is fairly in the middle of the visual spectrum, due to the spread resulting in white light. Due to the scattering of blue light by the atmosphere this white light is separated somewhat, resulting in a blue sky and a yellow sun.

(b) A lightbulb has a glowing wire with a somewhat lower temperature, resulting in yellow light, and something that is "red hot" is again a little less hot.

d. Longwave Radiation. The temperature of the Earth is much less than that of the Sun, approximately 288K (59°F/15°C), therefore the Earth emits radiation at a much longer wavelength than the Sun. The longest terrestrial wave is approximately 20 times longer than the longest shortwave. Both the Earth and the atmosphere emit longwave (terrestrial) radiation back towards space. However, just like with incoming solar radiation, not all longwave radiation that is emitted from the Earth reaches the edges of the atmosphere and out into outer space.

e. The Greenhouse Effect. If the Earth did not have an atmosphere, it would have surface temperatures far below freezing. It is the atmosphere that acts to heat the Earth's surface, and it is this role the atmosphere plays that is called the *Greenhouse Effect*.

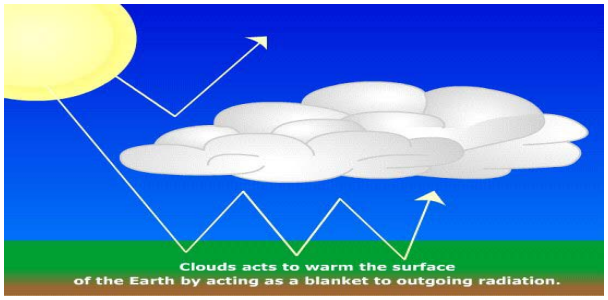

Figure 2 - Greenhouse Effect.

(1) Cloudless air is largely transparent to insolation, and therefore is partially absorbed by the surface of the Earth. Water vapor, carbon dioxide, and other trace gases in the atmosphere absorb a significant portion of the terrestial radiation emitted from the Earth. This energy acts to heat the atmosphere and increases the rate at which the energy is reradiated (Wien's Law) back to outer space and back to the surface of the Earth. The Earth then in turn absorbs and reradiates this energy and the game of "pass the hot potato" continues.

(2) The complicated game of "hot potato" acts to keep the surface of the Earth at a warm 59°F. Without the presence of water vapor, carbon dioxide and other constituents that composes our atmosphere, the Earth would be inhabitable for human life.

TRANSITION. Energy emitted from both the Sun and the Earth is extremely important. However, the location of the noon sun angle also plays an important role in the heating of the Earth's atmosphere and surface.

2. The Angle of the Sun.

a. Sun Angle. The angle that the Sun's rays strike the Earth has a direct impact on temperatures. With the noon sun (90° perpendicular to the surface) directly above a location (figure 2), that location will receive the most intense Sunrays that are concentrated in the smallest area. However when the angle of the Sun's rays begins to decrease, the intensity of the sunlight is not as intense because it has to (1) travel through a larger portion of the atmosphere and (2) cover a larger amount of the Earth's surface. This is why when the Earth is closet to the Sun in December; it is actually the winter season in the Northern hemisphere. The Sun's most direct rays are located at 23.5° South latitude, providing the Northern hemisphere with the less intense sunrays and therefore cooler temperatures. The "Analemma" is a chart used to calculate the location of the noon sun for any given latitude on any given day of the year.

Nassau, Bahamas Canton, Ohio Anchorage, Alaska

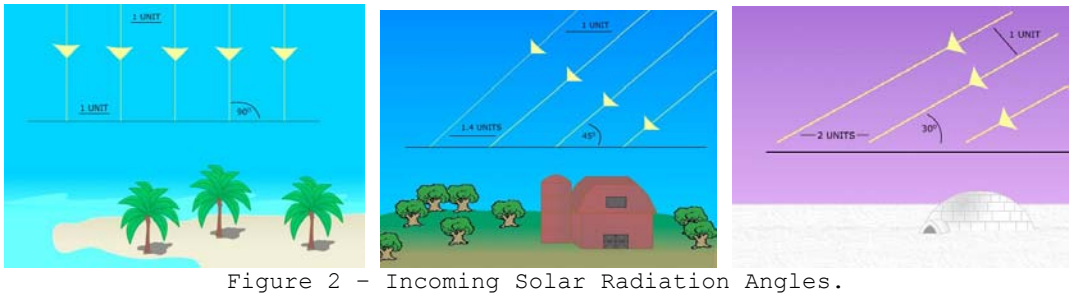

Figure 2 – Incoming Solar Radiation Angles.

b. Daylight and Darkness Hours. Recall from previous discussions, that the great circle of illumination represents the boundary that separates the dark half of Earth from the lighted half. The length of daylight versus darkness is determined by the location of the Earth in its orbit.

b. The length of daylight on June 21st in the Northern hemisphere is greater than the length of night. Comparing the fraction of the line of latitude that is on the "lighted" or dayside of the circle of illumination to the "dark" or night side establishes daylight length.

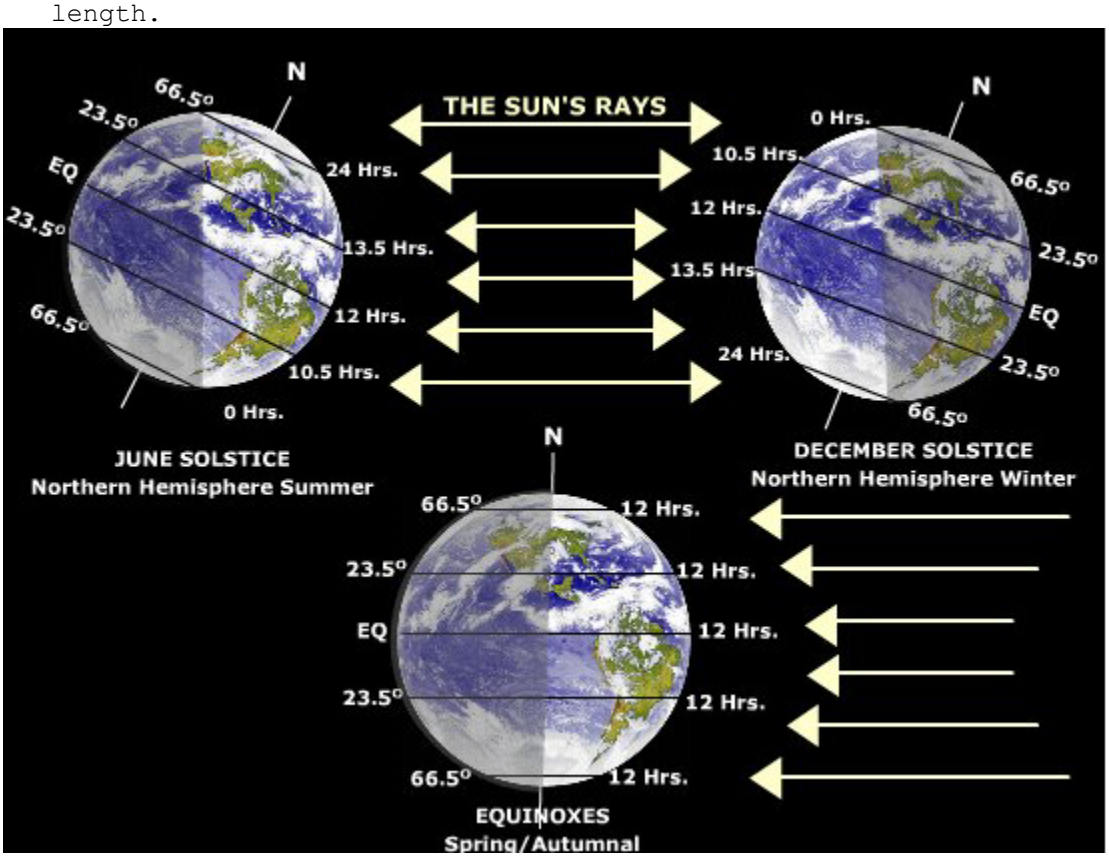

Figure 3 – Daylight and Darkness Hours.

c. View figure 3 and notice that on June 21st (June Solstice) all locations in the Northern hemisphere experience longer periods of daylight than darkness. The opposite is true in December, when the

length of darkness exceeds the length of daylight in the Northern hemisphere.

d. Using Table 1, the farther North of the Equator you are, the longer period of daylight you'll experience until you reach the Artic circle (66.5°N) where 24-hours of daylight is experienced. This is known as the "midnight sun", which does not set for six months at the North pole. These facts hold true for the opposite, the winter solstice.

Table 1 - Day Length at time of June Solstice.

Latitude	Day Length	Noon Sun Angles (degrees)	Latitude	Day Length	Noon Sun Angles (degrees)
90°N	24	23.5	10°S	11 h 32 min	56.5
80°N	24	33.5	20°S	10 h 55 min	46.5
70°N	24	43.5	30°S	10 h 12 min	36.5
60°N	18 h 53 min	53.5	40°S	09 h 20 min	26.5
50°N	16 h 23 min	63.5	50°S	08 h 04 min	16.5
40°N	15 h 01 min	73.5	60°S	05 h 52 min	6.5
30°N	14 h 05 min	83.5	70°S	0	0
20°N	13 h 21 min	86.5	80°S	0	0
10°N	12 h 43 min	76.5	90°S	0	0
0°	12 h 07 min	66.5			

e. It should now be evident why a midlatitude location is warmest during the summer months. It is then that the days are the longest and the angle of the Sun is at its highest.

OPPORTUNITY FOR QUESTIONS:

1. Questions from the Class. At this time, are there any questions concerning the material that was just presented to you?

2. Questions to the Class.

a. QUESTION. Provide an explanation of the "Greenhouse Effect" and its relationship with heating of the Earth's surface?

b. ANSWER. The greenhouse effect is when the Sun's radiant energy travels into the atmosphere but doesn't completely travel back out. This causes the temperature to be higher than it would be otherwise. It creates hotter weather and more radiation exposure.

REFERENCE.

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