ARM
CLIMATE RESEARCH FACILITY

Education and Outreach Lesson Plan

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Grade levels 10-12

Introduction to solar radiation
Effect of solar radiation on land and ice

An Overview of Solar Radiation

Objective

To compute the basic radiative "constants" of the sun-earth-atmosphere system.

Background information

The average temperature of the earth has remained approximately constant at about 15 degrees Celsius during the past century. It is therefore in a state of radiative balance, emitting the same amount of energy as it is receiving. One way of studying atmospheric processes is to construct an energy budget. Budgets are useful to indicate where material or energy comes from (sources) and where it goes (sinks). The enormous amount of energy available to the atmosphere is very apparent during storms. The Atmospheric Heat Budget shows where the atmospheric heat energy comes from and where it goes.

Practically all this energy ultimately comes from the sun in the form of the electromagnetic spectrum also known as electromagnetic radiation or electromagnetic waves. The sun's surface is extremely hot and radiates energy over a wide spectrum of wavelengths. The amount of heat energy received from the hot interior of the earth and from the stars is quite negligible by comparison.

It has been estimated that approximately 99 percent of the sun's radiation is contained in the wavelength range of 0.15 A (micron: 1 u = 10-1 in) to 4.0 u. If the wavelength of the radiation is short, the penetrating power of the wave is very high. Solar radiation is therefore known as short wave radiation.

Directly beneath the sun, the top of the atmosphere receives approximately 20 kcal per square meter per minute (1 cal = 4.18 joule and 1 kcal = 1000 cal = 4.18 x 101 joule). The incoming energy is distributed over the earth's surface as the earth rotates about its axis every 24 hours.

The basic laws of radiation apply to the sun-earth-atmosphere system. These laws include:

Stefan-Boltzmann Law

$$E^* = sT^4$$

where E^* = the blackbody irradiance [in $W\ m^{-2}$]
$s = 5.67 \times 10^{-8}\ W\ m^{-2}\ deg^{-4}$ (Stefan-Boltzmann constant)
T = the temperature of the radiating body [in degrees K]

This law states that the amount of energy radiated per unit time from a unit surface area (called the irradiance) of a blackbody is proportional to the fourth power of the absolute temperature of the object. A blackbody is a body which absorbs all of the incident radiation and emits the maximum amount of radiation possible at its given temperature.

Wien Displacement Law

l_{max} = 2897 / T

where l_{max} = the wavelength of peak emission [in micrometers (mm)]
T = the temperature of the radiating body [in degrees K]

This law states that the wavelength of maximum radiation emission for a blackbody is inversely proportional to its absolute temperature.

Activity
Students must have knowledge of the units Watts and Kelvin. They must have basic understanding of blackbody radiation as well as understanding of the electromagnetic spectrum. Each group of students will need the following

- Calculators
- Pencils
- Paper or lab notebook
- Diagram of the electromagnetic spectrum

Part I: Energy of the sun

1. The average temperature of the sun is 5780 K. Using the Stefan-Boltzmann Law, calculate the average irradiance of the sun.
2. The sun's radius is $7X10^8$ meters. How much total power is emitted from the sun?
3. Using the Wien displacement law, calculate the wavelength of peak emission of sunlight. What type of radiation does the sun emit primarily (e.g. ultraviolet, visible, infrared, etc.)? Use the diagram of the electromagnetic (EM) spectrum to remember the wavelength ranges of the EM bands.
4. If the ground temperature of the earth were 0 degrees Celsius, what would be the earth's irradiance and at what wavelength would this radiation be emitted? (Remember to convert temperature to Kelvin.) What type of radiation is this?

Part II: Energy received at the earth

1. The radiative energy from the sun striking a surface perpendicular to the sun's rays at the mean earth-sun distance is called the solar constant. The solar constant is denoted mathematically S_o. The inverse square law is used to calculate this constant:

   S_o = E(sun) x $(R(sun)/r)^2$

   where

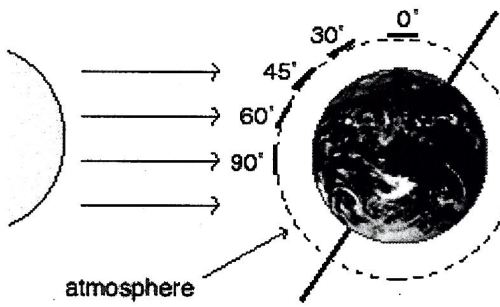
   E(sun) = irradiance of the sun

R(sun) = radius of the sun = $7x10^5$ km
r = mean distance between the earth and the sun = $1.5x10^8$ km

Calculate S_o.

2. Calculate the radiative energy at the top of the earth's atmosphere on a flat plane oriented at the following angles relative to the incoming solar rays:

   0 deg, 30 deg, 45 deg, 60 deg, and 90 deg



3. What can you say about the amount of radiation striking the top of the earth's atmosphere over different latitudes during an equinox?
4. If the radiative temperature of the sun were increased by 1%, what would be the new solar constant for the earth (assuming no other changes)? What percentage increase or decrease from your value of S_o (from Part II, Question 1) would this be?

The Effect of Solar Radiation on Land and Sea

Objective

Students will learn about the different heating properties of soil and water. They will understand why places near the sea have a more moderate climate than those inland.

Background information

When solar radiation reaches the earth, land surfaces absorb the energy in a different way to water surfaces. They heat and cool at different rates. Water takes longer to heat up than land, but once heated up, it retains its heat for longer than the land does. This is why, during the day-time, the sand on a beach gets much hotter than the water does particularly if the sand is black. At night time, the sea water-is warmer than the land! Therefore, places that are close to the sea, or near a large lake, have their temperatures moderated by the water, they will not be as hot as places inland during the day (or during the hot season), and they will not be as cool as places inland during the night (or during the cool season).

Most Pacific islands are so small that the temperature in most places is influenced by the sea, and the climate is known as *marine*. There is also very little variation between the temperature inland and the temperature on the coast. However, on some of the larger islands of Melanesia (Fiji, Vanuatu, Solomons, and Papua New Guinea), the effect of land and sea on temperature is noticeable, particularly on fine days and clear nights. We must remember that the height of the islands is also important because there will always be lower temperatures where the land is mountainous.

Activity

Each student or group of students will need the following:

- Bucket of soil and a bucket of water
- 2 ordinary thermometers
- Recording sheet (included in this packet)
- Normal graph paper
- Ruler and pencil

This lesson can only proceed if it is a clear, sunny day!

1. The group takes its buckets of soil and water outside the classroom and sets them up in direct sunlight.
2. After allowing 15 minutes for the sun to heat the soil and water, the group takes 2 temperature readings in the soil bucket, 0.5 centimeters below the surface, and the other about 7 centimeters below the surface. While this is being done, and using the other thermometer, 2 temperature readings are taken at the same depths in the water. Temperatures are recorded. It is important that the water is not stirred or disturbed during this experiment.

3. Both buckets are then left in the sun for a further 3 hours. The students will have to return to the buckets outside class time, and take further readings, 2 in each, at exactly the same depth as before. Temperatures are again recorded.

Student recording sheet

	Soil (15 min)	**Soil (3 h, 15 min)**	**Water (15 min)**	**Water (3 h, 15 min)**
Temperature (0.5 cm)				
Temperature (7 cm)				

Questions

1. Each student draws a graph to show his/her group's findings, and produces a short report on how soil and water behave when heated. Students should find that the soil temperature was much higher at half a centimeter below the surface than was that of the water. However, at a depth of 7 centimeters, the water should have been warmer than the soil. Reasons for this can be discussed with the class.
2. Each student will write answers to these questions:

- Why, after three hours in the sun, was the water temperature at a depth of 7 centimeters higher than that of the soil at a similar depth.
- Show, with a simple diagram, how the interior of a large flat island will be warmer during the day time than the coasts, and colder during the night.
- Explain what is meant by a *Marine Climate*. Why do most Pacific islands have what is called a *Tropical Marine climate*?