Science Partnership

The Earth's Energy Budget and Heating

Introduction

Solar radiation strikes an object and may interact in one of several different ways:

- *Absorption* - the radiation is absorbed, converted to heat and results in an increase in temperature
- *Transmission* - some materials are transparent to specific wavelengths and they may pass (transmit) through the object/material without absorption.
- *Reflection* and *scattering* are two similar processes that occur when radiation "bounces off" the object without being absorbed or transmitted.

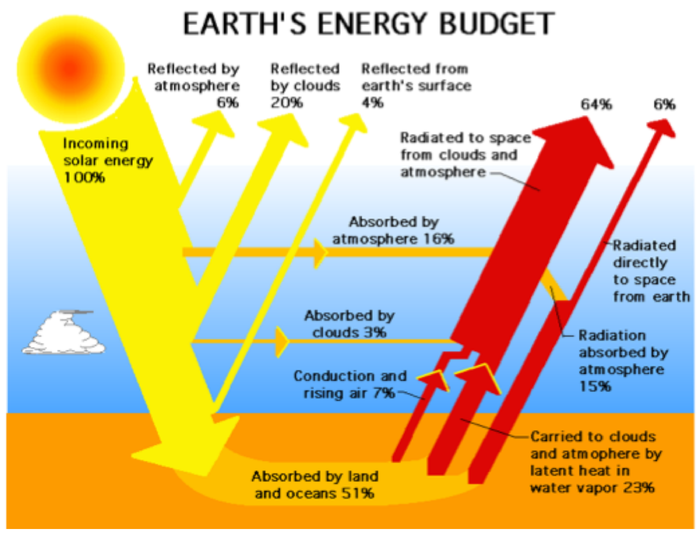


Figure 1. Earth's solar radiation budget. Source: *NASA*

Figure 1 shows that ~51% of incoming solar radiation is absorbed at the Earth's surface. Another 30% is reflected and scattered back to space by the atmosphere, clouds and the Earth's surface. An additional ~19% of incoming solar radiation is absorbed by clouds and gas molecules in the Earth's atmosphere.

Radiation may be absorbed, transmitted or reflected by an object and determines whether the object will change in temperature. The temperature of an object will increase as the amount of absorption of radiation by the object increases. Generally, objects that reflect or transmit light (little or no absorption) will experience little or no increase in temperature.

The *albedo* is the percent radiation returning from a given surface compared to the amount initially striking the surface – that is, it is a measure of a surface's *reflectivity*. Table 1 gives the albedos of common Earth surfaces.

Table 1. Albedos of some surface materials

Surface	Albedo (%)
Asphalt	5-10
Sand (white)	30-60
Soil (dark)	5-15
Soil (light)	25-30
Snow and Ice	80-90
Forest	5-10
Water	~8

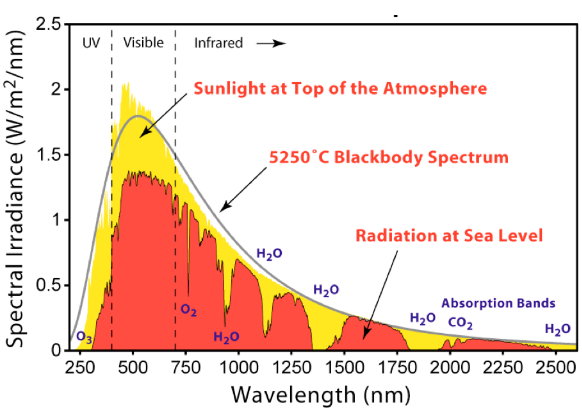


Figure 2. Solar radiation spectra at the top of the Earth's atmosphere and the Earth's surface.

Figure 2 shows that the Sun emits radiation across the electromagnetic spectrum but its maximum output is at relatively short wavelengths in the visible region of the spectrum (yellow curve). At the Earth's surface (orange curve), the decrease in the height of the spectrum is due to absorption, reflection and scattering by the Earth's atmosphere. In addition, it is clear that there are specific absorption bands where H_2O and CO_2 molecules in the atmosphere absorb infrared radiation. The difference between the two spectra is due to interactions in the Earth's atmosphere.

Figure 3 shows that the hotter Sun radiates more energy at shorter wavelength (visible region) than the cooler Earth. The left spectrum in the figure shows the solar output and the right spectrum shows the Earth's emission that peaks in the longer wavelength infrared region. Note that the spectral curves are not to scale (the Sun's output is ~6 orders of magnitude greater than the Earth's).

It is clear that a significant amount of the heating of the Earth's atmosphere is from the Earth's surface. Shorter wavelength radiation from the Sun is mostly transmitted through the Earth's atmosphere where it is absorbed by the Earth's surface, causing it to increase in temperature. The Earth' reradiates the energy at longer infrared wavelengths.

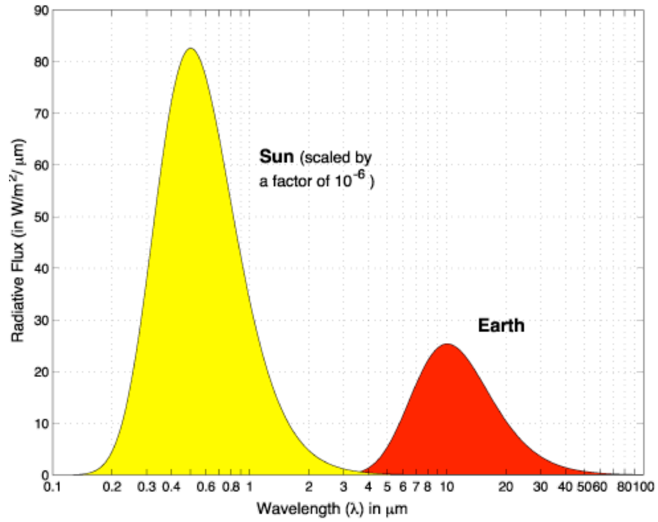


Figure 3. Schematic spectral emission (blackbody) curves of the Sun and Earth.

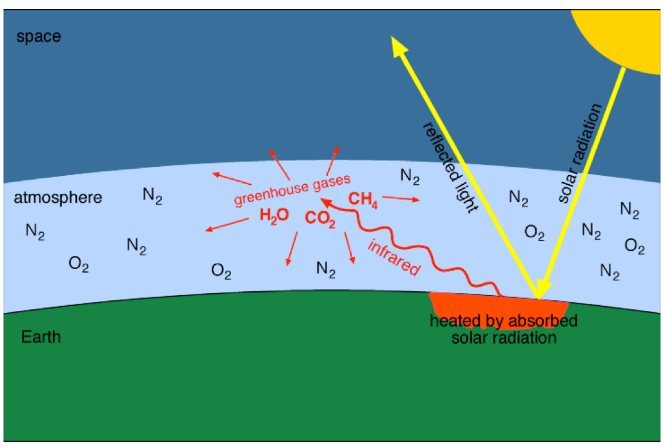


Figure 4. Schematic diagram showing that shorter wavelength radiation from the Sun heats the Earth's surface. The Earth's surface emits infrared radiation that is absorbed by molecules in the Earth' atmosphere.

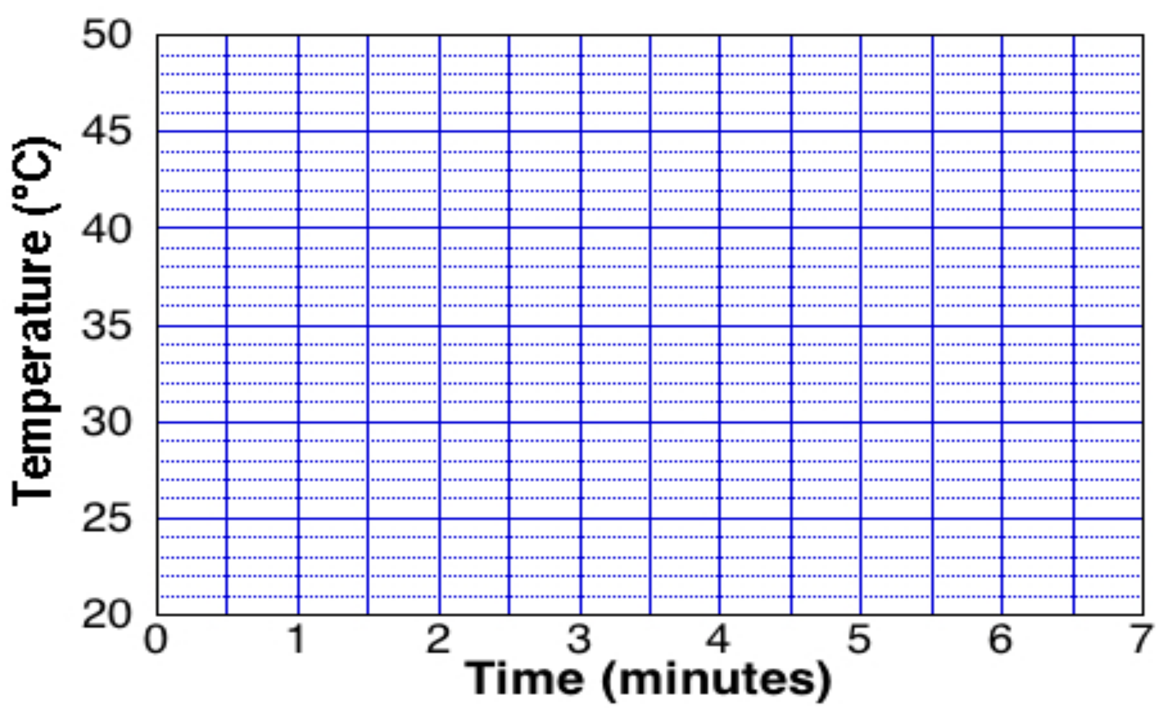
Figure 4 shows that longer wavelength infrared radiation coming from the Earth's surface is absorbed by H_2O, CO_2 and other molecules in the Earth's atmosphere. The absorption of the infrared radiation from the surface causes the Earth's atmosphere to increase in temperature. The Earth's atmosphere may be heated by increasing the proportion of molecules (such as CO_2) in the atmosphere that absorb infrared radiation.

Part 1. Albedo Experiment

This experiment is designed to give a better understanding of the role of albedo in the heating of the Earth's surface. Table 1 shows that different surface materials have different albedos. Before you begin the experiment, answer question 1 below.

1. Obtain the following materials:
   - silver can with lid
   - black can with lid
   - 2 thermometers
   - high intensity incandescent light
   - chemistry stand to attach light
   - timer
2. Attach the light to the stand so that it is oriented horizontally.
3. Place the thermometers through the lids on the cans and make sure that the scale on the thermometer is readable. Also ensure that the thermometer is placed the same way in each can.
4. Position the cans about six inches from the light making certain that they are the same distance from the light and will receive the same amount of radiation. Make sure that the cans are not touching one another.
5. Before you begin the experiment, answer question 1 below.
6. Record the temperatures of each can before turning on the light (at time 0).
7. Turn the light on and record the temperatures of each can every 30 seconds for 6 minutes and record your data in the table.
8. Plot the temperatures from your data table on the graph. Connect the points for each data set and be sure to label the curves (black or silver can).

Time (min.)	Temp. of black can	Temp. of silver can
0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		
3.5		
4.0		
4.5		
5.0		
5.5		
6.0		



1. The cans will be heated with the lamp. Before you begin the experiment, predict which can (black or silver) will show the greatest amount of increase in temperature and explain your reasoning.

2. Did you confirm your prediction or did you get different results?

3. Write a brief summary of your albedo experiment and explain your results.

4. For each can, calculate the rate of heating (the change in temperature divided by the time).

Black can = __________°C/6 minutes   Silver can = __________°C/6 minutes

=_________________°C/minute   =_________________°C/minute

5. In table 1, review the albedos of different Earth surfaces. Compare the albedos and dark soil and ice/snow. What would be the affect of albedo on the heating of each of these surfaces?

6. The Earth's average albedo (the reflectivity of solar radiation back into space) is ~30%. One of the consequences of global warming is the melting of ice and snow surfaces at high latitudes. What will be the affect on the Earth's albedo if the polar ice caps were gone? What would be the affect on the global temperature if the polar ice caps were gone? Explain your answers.

7. If you lived in a warm and sunny climate, what would be the best choice for a colored roof (light or dark) to keep your home cool? Explain your answer.

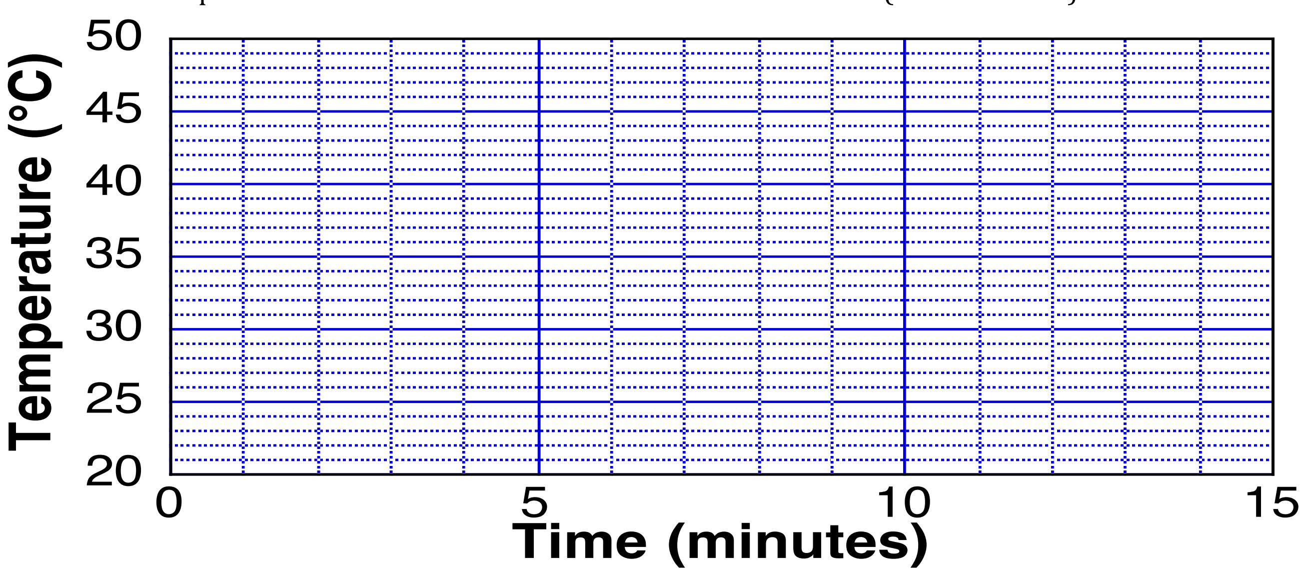
Science Partnership

Part 2. Experiment on the Differential Heating of Land and Water

In this experiment, you will investigate the differential heating of land (sand) and water. Different surfaces may heat up at different rates which may influence the temperature of the air above the surface. Before you begin the experiment, answer question 1 below.

1. Obtain the following materials:
   - 2 beakers
   - 2 thermometers
   - dry sand
   - water at room temperature
   - high intensity incandescent light
   - chemistry stand to attach light
   - timer
2. Fill one beaker ¾ full with dry sand and the other beaker ¾ full with water at room temperature.
3. Place the thermometers in the beakers so that the thermometer bulb is just below the surface. You may need a wooden stick to suspend the thermometer in the beaker.
4. Suspend the light from the chemistry stand (facing down) and place the beakers beneath the light so that the light is as close to the top of the beakers as possible. Make certain that they are the same distance from the light and will receive the same amount of radiation.
5. Record the temperatures of each beaker before turning on the light (at time 0).
5. Turn the light on and record the temperatures of each beaker every minute for 10 minutes and record your data in the table.
6. After 10 minutes, turn off the light and record the temperatures of the beakers every minute for 5 minutes (total 15 minutes) in the table.
6. Plot the temperatures from your data table on the graph. Connect the points for each data set and be sure to label the curves (sand or water).

Time (min.)	Temp. of sand	Temp. of water
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		



Science Partnership

1. The sand and water will be heated with the lamp. Before you begin the experiment, predict which beaker (sand or water) will heat up more quickly and explain your reasoning.

2. Did you confirm your prediction or did you get different results? Which material heats more quickly?

3. Write a brief summary of your experiment and explain your results.

4. If both the sand and water were exposed to the same amount of radiation, suggest a reason that they heat and cool at different rates.