The Role of the Atmosphere and Greenhouse Effect in Determining the Surface Temperature of the Earth

Methane Project Interactive Lesson

Developed at the
Institute on Climate and Planets, NASA Goddard Institute for Space Studies
by
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To use the interactive courseware module described in this lesson, you will need:

- a PC running Windows 95 / 98 / NT
- a web browser: Netscape Navigator or Internet Explorer
- plug-in “Neuron” installed
  (available from http://www.asymetrix.com/products/toolbook2/neuron/index.html)
- the module loaded into your web browser
  (at http://icp.giss.nasa.gov/education/courseware/plntgrhs.tbk)

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To the Teacher

Learning Objectives: at the end of this lesson, students will be able to:

- Use a model to investigate the relationship between radiative balance and the earth’s surface temperature, conducting three experiments: scenario 1 - with no atmosphere, scenario 2 - an atmosphere without greenhouse gases, and scenario 3 - an atmosphere and greenhouse gases.
- Use graphical data to investigate the historical trends in greenhouse gas concentrations.
- Calculate the percent change in greenhouse gas concentrations for a given time period
- Use a model to see the effect of the percent change in greenhouse gases might affect global temperature.

Methodology: you will need to access the courseware module at the web site listed above.

- For Sections 2 and 3 of the activity sheet, the teacher could take students through each step, explaining what the module shows as you move through it or the students may do it on their own as they go through the questions.
- For Sections 4 and 5 of the activity sheet, the students should get the data from the graphs, do the calculations to find the percentage change in greenhouse gas concentrations. Then use those values in the courseware module to find the change in global temperature that might result from those increases in greenhouse gas concentrations.

1. Background Information

The surface temperature of the earth results from the combined effects of several factors. The dominant factor is the amount of solar energy arriving from the sun, which depends upon the earth's distance from the sun. On the average, the Earth is about 150 million kilometers (km) [about 96 million miles] from the sun. We refer to this distance as 1 astronomical unit.

When solar energy reaches the earth, some of it is reflected by the atmosphere. Most of the remainder passes through the atmosphere, reaching the earth's surface. At the surface, some of the energy is reflected and some is absorbed. By comparing the amount of energy reflected to the total energy received we can determine the reflectivity or albedo of the earth. Albedo is defined as the amount of energy reflected divided by the amount of energy received and can be calculated at the top of the atmosphere or at the surface. The albedo is another factor affecting the earth's surface temperature.

As the surface of the earth absorbs solar energy, the surface warms up and then radiates energy, mostly as infrared, back into the atmosphere towards space. Some of the naturally occurring gases in the earth's atmosphere absorb some of this infrared energy. These gases warm, and in turn radiate infrared energy of their own in all directions, some of which is absorbed by the surface giving it additional energy. This process is the natural greenhouse effect.

The earth's surface receives solar energy and energy reradiated by gases in the atmosphere. It heats and radiates energy back into space. This continues until the amount of energy received at the surface is equal to the amount of energy radiated back into space. This condition is called radiative balance. When this occurs the temperature is stable.

Using an interactive courseware module, we will explore the effect of an atmosphere and natural greenhouse gases on the surface temperature of the earth with three scenarios. We will also look at natural and human caused (anthropogenic) perturbations in greenhouse gas concentrations and their possible effects on earth's surface temperature. Use the table below for temperature conversions. *Before proceeding, please make sure you acquire the module and meet the computer requirements described on the cover page of this lesson.*

Kelvin =	°Celsius =	°Fahrenheit	Kelvin =	°Celsius =	°Fahrenheit	Kelvin =	°Celsius =	°Fahrenheit
250	-23	-9.4	265	-8	+17.6	280	+7	+44.6
253	-20	-4.0	270	-3	+26.6	285	+12	+53.6
255	-18	-0.4	273	0	+32.0	288	+15	+59.0
258	-15	+5.0	275	+2	+35.6	290	+17	+62.6
260	-13	+8.6						

2. Surface Temperature - No Atmosphere (SCENARIO ONE)

We will now look at what the earth's surface temperature would be if there were no atmosphere. Begin the simulation program by following the prompts until you have "the earth with no atmosphere". *Be sure to read the information in the dialog boxes as they appear.*

- What is the initial surface temperature? [ ] K = [ ] °C = [ ] °F
- Describe what happens to solar energy after it reaches the surface. ____________________________

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As you continue through the program, note the following information:

- Describe what happened to the amount of radiated energy as the surface heated. ____________________

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- At the final step how many units of solar energy were available to be absorbed by earth's surface? ______

______

- At the final step how many units of energy were radiated back? ______
- How do you know that radiative balance was reached? (No, it isn't because it said so.) ______

______

______

- What was the surface temperature when radiative balance was reached? ☐ K = ☐ °C = ☐ °F

3.a. Surface Temperature - With an Atmosphere and No Greenhouse Gases (SCENARIO TWO)

We will now investigate what the earth's surface temperature would be if we had an atmosphere without and then with greenhouse gases. Begin the simulation program by following the prompts until you have the "earth with an atmosphere but no greenhouse effect".

- How many units of solar energy were available to be absorbed by the earth's surface? ______
- How does this compare with the amount of solar energy that was available to be absorbed by the surface when there was no atmosphere? ______

______

- What was the surface temperature when radiative balance was reached? ☐ K = ☐ °C = ☐ °F
- Compare the surface temperature reached at radiative balance when there was no atmosphere to the temperature when there was an atmosphere? Why were they different? ______

______

3.b. Surface Temperature - With an Atmosphere and Greenhouse Gases (SCENARIO THREE)

Continue by adding natural greenhouse gases to the atmosphere.

- How many units of solar energy were available to be absorbed by the earth's surface? ______
- How many units of energy are being radiated by the earth's surface? ______
- How could the amount energy being radiated by the surface be more than the amount of solar energy received? ______

______

- What was the surface temperature when radiative balance was reached? ☐ K = ☐ °C = ☐ °F

4. Natural Changes in Concentrations of Greenhouse Gases

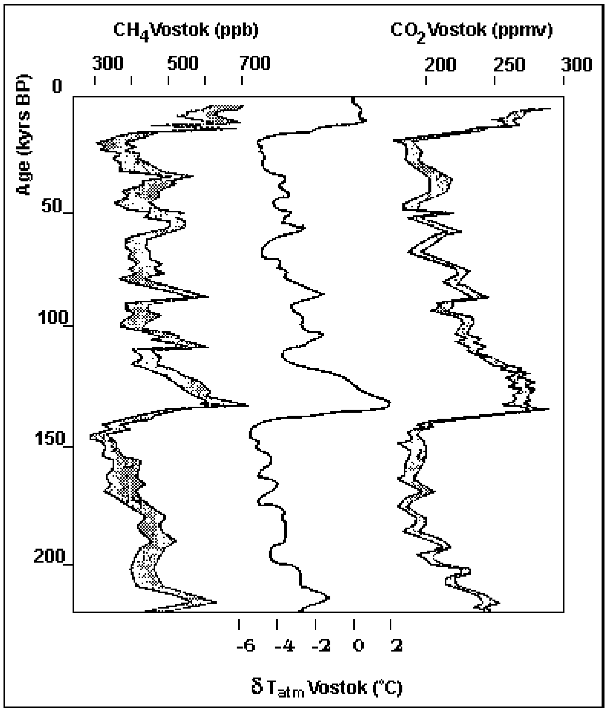

Figure 1. The climatic record obtained from the isotopic composition of the Vostok ice core compared to atmospheric CO_2 and CH_4 concentrations obtained from ice bubbles. (Lorius, C. and H. Oeschger, 1994)

The previous exercises showed that the greenhouse effect occurs naturally and actually is beneficial. On the earth, water vapor (H_20), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the gases most responsible for this effect. The graph on left (figure 1) shows concentrations of atmospheric methane and carbon dioxide in the atmosphere, as well as temperature changes that occurred over the last 200,000 years. The data were obtained from examining gases trapped in ice cores from Vostok, Antarctica. The y-axis (kyrs BP) shows the time in thousands of years before the present. The x-axis on top shows the concentration of methane in parts per billion in a given volume (left) and the concentration of carbon dioxide in parts per million in a given volume (right). The x-axis on the bottom (center) shows variations around the mean temperature over this time. Notice that even during periods where concentrations are generally decreasing, there are oscillations to higher and lower values. These are natural variations in the concentration of greenhouse gases.

- What is the time period covered by the graph? ____________________

	CO_2	CH_4	Temperature
What is the maximum concentration of CO_2 and CH_4 and temperature 140,000 years ago? (this is our initial value)	pmv	ppbv	°C
What is the minimum concentration of CO_2 and CH_4 and temperature 20,000 years ago? (this is our final value)	pmv	ppbv	°C
What was the change in CO_2 and CH_4 and temperature for this period?	pmv	ppbv	°C
Did they increase or decrease?			
Calculate the percentage change for CO_2 and CH_4 $\% \text{ Change} = \frac{\text{Change}}{\text{Initial Value}}$			

We can now use the simulation program to see what temperature changes might occur with the change in concentrations of CO_2 and CH_4 that we calculated from the ice core data. Go to the program and follow the prompts until you get to the "change greenhouse gases" dialog box. Choose CO_2 first and change the percentage to the value you calculated.

- What is the change in temperature? [   ] K = [   ] °C = [   ] °F

Repeat the procedure for CH_4.

- What is the change in temperature? [   ] K = [   ] °C = [   ] °F

- How does the combined temperature change shown by the program compare to the change given in the graph? ____________________

- Why do you think this happened? ____________________

5. Anthropogenic Changes in Concentrations of Greenhouse Gases

Since the beginning of the Industrial Revolution about 200 years ago, human activities (anthropogenic) have been influencing the concentration of greenhouse gases. Examine the graph on the right (figure 2). This graph shows the atmospheric concentration of CO_2 for the past 200 years. This type of graph shows concentrations as well as trends over time. The y-axis shows concentration of CO_2 in parts per million in a given volume - ppmv . The x-axis shows the years the measurements were taken. Note that the data line is not straight. This means that the rate of change is not constant for the entire time.

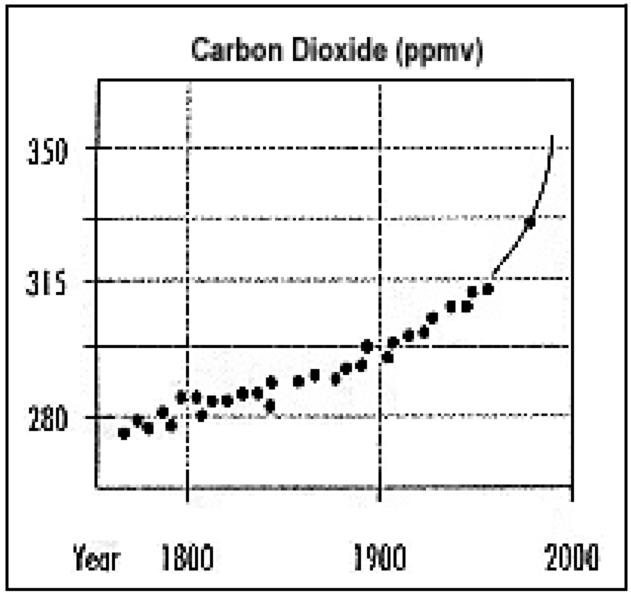

Figure 2. Increase in CO_2 since the 18th century. Data from analyses of air bubbles in ice cores of known age and, for recent decades, from atmospheric measurements. (Lorius, C. and H. Oeschger, 1994)

- What is the approximate change in concentration of CO_2 from 1800 to 1900? ________________ ppmv
- What is the approximate change in concentration of CO_2 from 1900 to 1990? ________________ ppmv
- Calculate the percentage change in CO_2 concentration from 1800 to 1990. ________________

Put this value into the simulation program.

- What is the resulting change in temperature? [ ] K = [ ] °C = [ ] °F

Examine the graph below (figure 3). This graph shows the atmospheric concentration of CH_4 for the past 200 years. The y-axis shows concentration of CH_4 in parts per billion in a given volume - ppbv. The x-axis shows the years the measurements were taken.

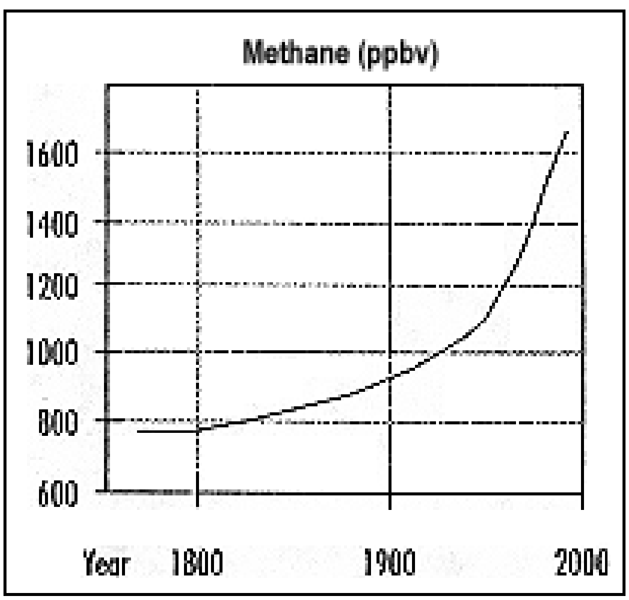

Figure 3. Increase in CH_4 since the 18th century. Data from analyses of air bubbles in ice cores of known age and, for recent decades, from atmospheric measurements. (Lorius, C. and H. Oeschger, 1994)

- Is the change in methane concentration constant for the entire time period shown? ________________

  ____

- Calculate the percentage change in CH_4 concentration for 1800 to 1990. ________________

Put this value into the simulation program.

- What was the resulting change in temperature?

  [ ] K = [ ] °C = [ ] °F

Examine the graph on the right (figure 4). This graph shows the atmospheric concentration of Nitrous Oxide (N_2O) in parts per billion for a given volume for the past 200 years.

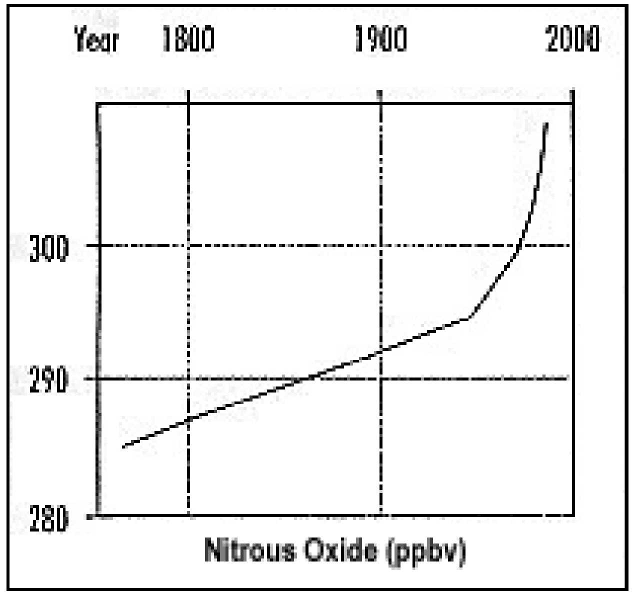

Figure 4. Increase in Nitrous Oxide since the 18th century. Data from analyses of air bubbles in ice cores of known age and, for recent decades, from atmospheric measurements. (Lorius, C. and H. Oeschger, 1994)

- Using the graph, determine when the greatest rate of change occurred? ______________________

____

____

- Calculate the percentage change in N_2O concentration from 1800 to 1900. ______________________

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Put this value into the simulation program.

- What was the resulting change in temperature?

[ ] K = [ ] °C = [ ] °F

6. Critical Thinking

- Using the information you derived from the 3 graphs, what pattern seems to emerge regarding the rate at which the concentration of these greenhouse gases are increasing? ______________________

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- What prediction could you make if these trends were to continue? ______________________

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Reference

Lorius, C. and H. Oeschger, Paleo-perspectives: Reducing Uncertainties in Global Change?, *Ambio: A Journal of the Human Environment*, 23(1), 30-36, 1994.