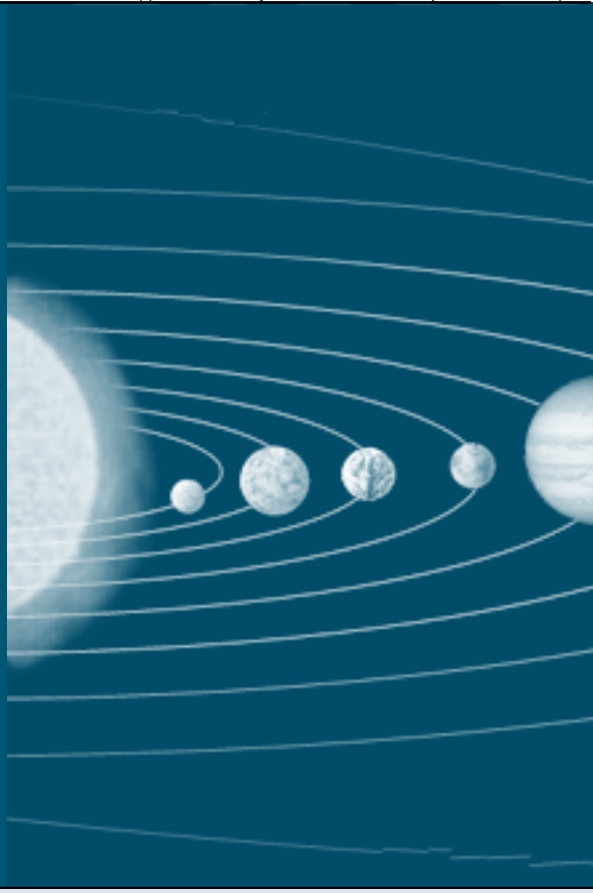
# What Determines a Planet's Climate?



## Student Activities

*A curriculum project of the NASA Goddard Institute for Space Studies in collaboration with the Earth Institute at Columbia University.*

## To The Student

Earth is a planet that is friendly and hospitable to human habitation. Even though it includes the frozen ice caps of the Antarctic and the hot sands of the Sahara, for the most part our planet has climate conditions that make for pleasant living with only minor adjustments. As far as we know, however, Earth is the only planet with a climate that is so favorable to humans. On some of our closest neighbors we find temperatures 500 degrees Celsius higher or 100 degrees Celsius colder than those found on Earth. Why is this the case? What is it that makes the climate of Earth so much more hospitable than the climates of other planets? This is the 'burning' question that will be investigated in this class. Your investigations will involve a variety of hands-on activities with scientific instruments, mathematical calculations with computer models, and simulations of natural processes – techniques used daily by scientists across the world.

# What Determines a Planet's Climate?

By the Institute on Climate and Planets

A curriculum project of the NASA Goddard Institute for Space Studies
in collaboration with the Earth Institute at Columbia University.

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April 2004
(Revised August 2005)

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Topic

# 1 Temperature Variations and Habitability


**Activity A** Observing, Describing, and Adapting to Environmental Variations

**Activity B** Relating Factors that Influence Planetary Temperature and Habitability

# Considering a Real World Problem

## *Searching for Life in Extreme Environments*

### *The Problem*

A wide range of environmental conditions characterizes regions around the globe. What factors or conditions do you think are essential to sustain human life and how do they interact to produce a habitable temperature? What locations on Earth do you think represent the most extreme environmental conditions in which human life can survive? Based on what you have learned and discussed with your classmates, indicate the magnitude of the differences in these environmental conditions.

Consider the extremely high temperatures inhabited by microorganisms in Yellowstone National Park. Are there other extreme environments on Earth where scientists can search for life forms other than human? Based on the ideas discussed in this topic, what are the implications for the existence of life on other planets?

From this initial study of some of the extreme temperatures that exist on Earth and other planets in our solar system, offer your perspective on the types of negative and positive consequences that may occur if adjustments or changes are made to the essential factors or conditions that make Earth a habitable planet.

**Figure 1.1. Wyoming's Yellowstone National Park is one of the most famous geologic landmarks in the United States. In addition to the dramatic canyon landscape, water boils in geysers and hot springs up to 92°C (198°F). While such temperature extremes are not hospitable to humans, microorganisms such as bacteria live and grow in these environments.**

# Activity A

## Observing, Describing, and Adapting to Environmental Variations

### Overview

We experience temperature variations where we live. We also know that people around the globe live in environments with conditions different from ours. Environmental conditions that exist on planets within our solar system differ greatly from Earth, even on our closest neighbors, Mars and Venus.

Collectively, the class will decide upon a plan for describing the day, including general observations and specific measurements. Two teams will be set up to describe the indoor and outdoor environments. Several instruments will be available to collect data. Data is to be recorded and compared. The References provide data on environmental conditions at other Earth locales and planets in our solar system. These will be used to discuss temperature ranges that exist, their relation to habitability, and ways to adapt to these conditions.

### Learning Objectives

- ✓ Identify a minimum of five factors useful in describing local environmental conditions.
- ✓ State the range of temperature variability on the earth.
- ✓ State the range of temperature variability within our solar system.
- ✓ Explain the connections among quality of life on Earth, temperature variability, and the environment.

### Relevance

How do humans modify their environment to make it more livable or habitable? This is an important question as it concerns the resources needed to adapt to environmental conditions. It also relates to the consequences on human health and economic productivity if we cannot make necessary adjustments. Finally, this question is connected to human exploration of other inhospitable planets and our ability to adapt to these environments using scientific inventions.

# Observing, Describing, and Adapting to Environmental Variations

## Materials

Access to the outdoors, instruments to measure weather phenomena (thermometers, barometers, anemometers, etc.), images of Earth and other planets that represent temperature extremes.

## Methods

### Preliminary Discussion and Planning

1. Determine a plan for describing the indoor and outdoor environment by identifying the observations to make, as well as measurements needed to quantify your descriptive statements.
2. Divide into two investigation teams, one to study the indoor environment and the other outdoors.

### Observations

1. Take 15 minutes to make your observations and collect measurements.
2. Record your data on the Data Sheet: Observing and Describing the Day.

### Data Analysis, Comparisons, and Consensus

1. Exchange observations in class. Are there differences or similarities? What is the magnitude of the differences, if any?
2. Discuss: How do humans modify their environment to make it more livable?
3. Study the Reference viewgraphs of sites in the Sahara and the Antarctic.
4. Discuss: What if this activity were moved to these locales? How do we adapt to these environments?
5. Study the References of the atmospheric and surface features of Earth and other planets.
6. Discuss: What are the temperature ranges? Magnitude of differences? Why is Earth special to humans?

### Investigation Notebook

1. Your plan for taking measurements that describe the day.
2. Data Sheet: Observing and Describing the Day.
3. Questions: Observing and Describing the Day.

# Observing and Describing the Day

## Task

In a few moments, part of the class will go outside with the goal of describing the conditions they encounter outdoors. They will want to make as complete a description as possible. The other part of the class will remain in the classroom and describe the conditions there as completely as possible. Before separating, the class should decide which factors they will investigate and measure, and any precautions that should be taken to ensure accuracy.

Break up into groups of five students each. Each group of students must decide in 10 minutes how they will go about describing the conditions of their assigned location. After they have decided what they would like to describe, they will determine what tools they may need and ask the teacher for those tools.

All the groups will then go to their respective locations and make their observations. Record these observations in the table below. In each box write the type of measurement being taken and record the observation. For example, if you are outside and observe cloudy sky conditions with your sight, your box can read: Eyeball Sky Conditions/Cloudy. When the groups reassemble in the classroom, each group will present its description to the class.

## Location

Circle the location your group is observing: **Indoor** **Outdoor**

## Observations

| Student 1 | Student 2 | Student 3 | Student 4 | Student 5 |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Table 1.1. Observations of Local Conditions**

# Observing and Describing the Day

1. What are the differences and similarities between environmental conditions indoors in the classroom and outdoors? What is the magnitude of the differences?

2. How do humans modify the environment to make it more livable?

3. If this activity were moved to the Sahara or the Antarctic, how could we adapt to those environments?

4. What makes Earth special to humans?

5. Consider the temperature differences that exist between Earth and Mars, and Earth and Venus. Do regions exist on Earth that can experience similar high or low temperature differences? Use the map in figure 1.2 below to answer this question. If yes, identify these regions and the temperature ranges. Calculate the magnitude of these temperature differences. For example: Region X's highest recorded temperature was 40 degrees higher than Region Y's lowest recorded temperature. Relate these differences to the temperature differences found between the planets.

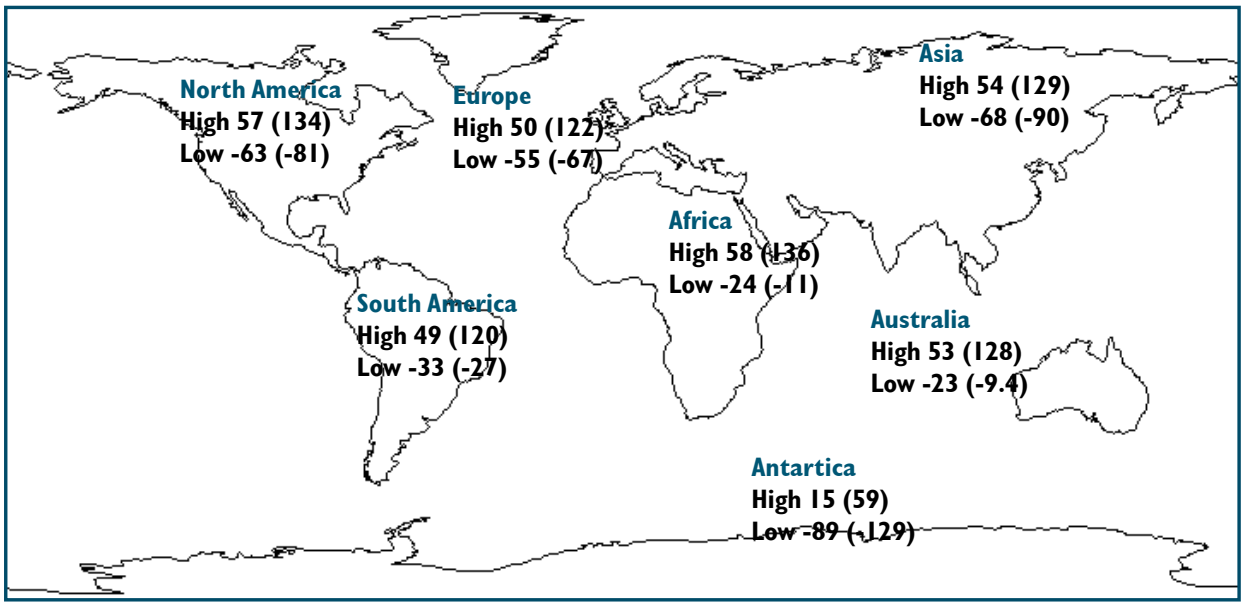



**Figure 1.2. Global Measured Temperature Extremes [in ° Celsius (° Fahrenheit)].**

# The Sahara and the Antarctic

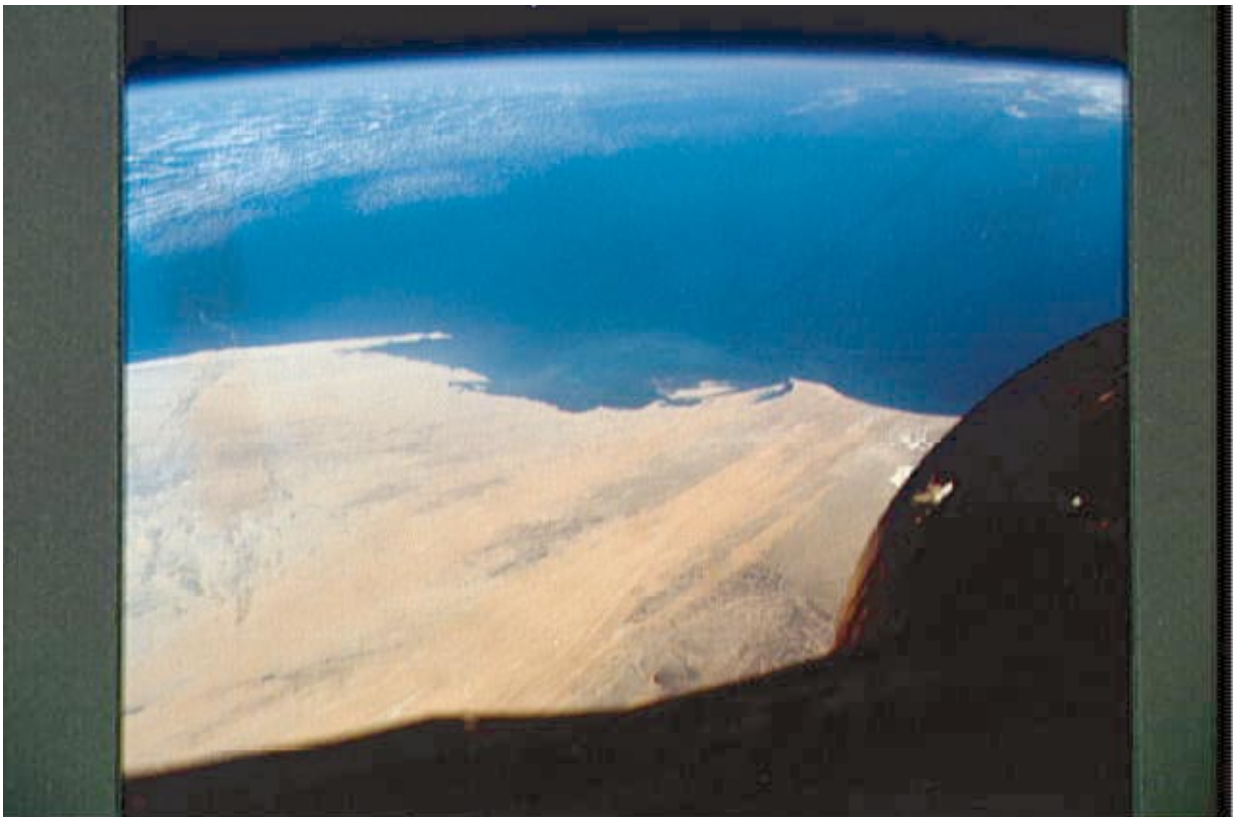


**Figure 1.3. A view of the Sahara from space.**

**Figure 1.4. Antarctic ice.**

# Earth, Mars, Venus and Pluto

Figure 1.5. Earth.

Figure 1.6. Mars.

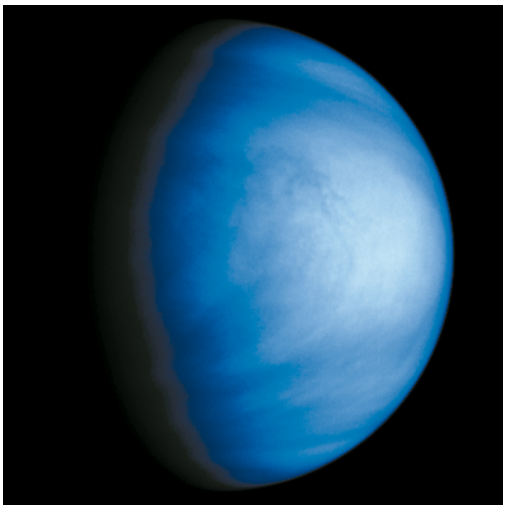


Figure 1.7. Venus.

Figure 1.8. Pluto and its moon Charon.

# Comfort Adjustments in Our Solar System

Comfortable Temperature = 21ºC (70ºF)

| Place | Average Temperature ºC (ºF) | Comfort Adjustment ºC (ºF) |
|---|---|---|
| Sahara Desert | 32.2 *(89.9)* | –11.2 *(–19.9)* |
| Sahara Desert (extreme) | 57.7 *(135.9)* | –36.7 *(–65.9)* |
| Antarctica | –70 *(–94)* | 91 *(164)* |
| Antarctica (extreme) | –89.2 *(–128.6)* | 110.2 *(198.6)* |
| Earth | 15 *(59)* | 7 *(11)* |
| Venus | 458 *(856)* | –437 *(–786)* |
| Mars | –60 *(–76)* | 81 *(146)* |
| Pluto | –223 *(–370)* | 244 *(440)* |

**Table 1.2. Adjustments to temperature extremes to achieve a "comfortable" temperature.**

# Activity B

## Relating Factors that Influence Planetary Temperature and Habitability

### Overview

Planetary systems have basic inputs and variables that produce average temperature and influence habitability. Some of these inputs and variables have been discussed in the previous activity where you identified certain modifications humans need to do in order to make their immediate environment more comfortable and livable. How these inputs and variables interact is an important step in understanding their influence on planetary temperature and habitability.

Your teacher will divide the class into small teams to construct a "knowledge map" of the essential characteristics or factors of a planet with a habitable climate. Each Knowledge Map represents a group's consensus about the 10 essential factors needed for a habitable planet and the relationships among them.

### Learning Objectives

- ✓ Give three examples of how humans modify the environment to improve livability.
- ✓ Identify three factors that may determine the average temperature of a planet.
- ✓ Identify a minimum of five factors that may determine the habitability of a planet.
- ✓ State the importance of maintaining habitable temperature on a planet.
- ✓ Briefly describe the links between two sets of factors of your choosing.

### Relevance

Even under some of the most extreme conditions here on Earth – the Antarctic and the Sahara – humans have been able to make the necessary modifications to live (at least briefly) in these places. As humanity begins to explore other planets in our solar system, the idea of what makes a place habitable takes on a wider meaning, especially when humans begin to set foot in these remote areas.

What determines the habitability of a place? What are the major factors that determine the habitability of a place located anywhere in our solar system? How are these factors related to one another?

# Relating Factors that Influence Planetary Temperature and Habitability

## Materials

Post-it™ (or similar) notes, colored linking strips made by cutting index cards lengthwise, large sheets of poster paper, and markers.

## Methods

### Preliminary Discussion and Planning

1. Each group should select one person as a recorder to diagram the Knowledge Map.
2. Discuss and make a list of approximately 10 essential characteristics or factors and then write each characteristic on a separate Post-it™ note at your table.
3. Discuss some of the possible relationships among the factors.

### Preparing the Knowledge Map

1. Group the Post-it™ notes that are most closely related together on a large poster sheet.
2. Indicate strong relationships using the linking strips. Place these links between the related Post-it™ notes and write a brief explanation of the relationship next to each link. Be prepared to explain why you chose your characteristics, how they are related, and how they contribute to forming a planet with a habitable climate.

### Defending the Knowledge Map

1. After each group has completed its Knowledge Map, the groups will be divided into Presenters and Questioners.
2. Questioners will be assigned the task of examining the Knowledge Maps of a group. The Presenters will explain their choices and the relationships they have indicated within the Knowledge Map. The Questioners are then free to ask questions about the map or the relationships. A different member of the presenting group should answer each question.
3. All Questioners complete a Knowledge Map Assessment Data Sheet as the evaluation for the group they questioned.

### Investigation Notebook

1. Data Sheet: Knowledge Map.
2. Date Sheet: Knowledge Map Assessment.
3. Questions: Relating Factors that Influence Planetary Temperature and Habitability.
4. Essay: Topic 1: Searching for Life in Extreme Environments.

# Knowledge Map

Draw a diagram of the Knowledge Map your group created. Label the planetary system inputs, variables, and outputs.

Number the links in your diagram and explain the relationships below.

# Data Sheet — Activity B

## Knowledge Map Assessment

**Presenting Team** _____

**Questioning Team** _____

| Evaluation Criteria | Requirements for the Criteria | Comments | Completed (place ✓ if criteria met) |
|---|---|---|---|
| A minimum of 10 habitability factors selected. | All 10 factors must relate to habitability for humans. | | |
| The reason for selection of each factor must be explained adequately. | The group must give a short, valid explanation as to why they selected each factor. | | |
| A minimum of three relationships between factors must be shown. | There should be three connecting to a maximum of two factors. | | |
| The nature of each of the links should be explained clearly. | The group should be able to clearly and accurately explain their indicated links. | | |
| The overall Knowledge Map should be clear and logical. | The 10 factors and links should be arranged clearly and logically. The Knowledge Map should be easy to read. | | |

### Additional Comments:

# Relating Factors that Influence Planetary Temperature and Habitability

1 .What are some of the factors that determine the habitability of a place?

2. What are some of the essential factors that determine the habitability of a place located anywhere in our solar system?

3. How are these factors related to one another to produce a habitable climate?

# Searching for Life in Extreme Environments

Write a 300 word essay that responds to the questions in this topic's Real World Problem (refer to page 6). You should use at least one reference in your essay. Consider the following: encyclopedia, science magazines, textbooks, the Internet. Be sure to cite the reference(s) you decide to use.

Topic

# 2

# Modeling Hot and Cold Planets


**Activity A** Modeling Hot and Cold Planets

**Activity B** Experimenting with Computer Models

**Activity C** (optional) Approximating the Average Surface Temperature of the Earth

# Considering a Real World Problem

## *Preparing for Mars Living in an Arctic Outpost*

One of NASA's long-term goals is to create a human habitat on Mars. Interest in this mission has lead to a funded project to construct an experimental facility on Earth where scientists and engineers can develop and test technical and human capabilities to live on a Mars outpost.

**Figure 2.1. Painting of the Mars Flashline Arctic Research Station.**

This mission is a project of the Mars Society. One of the first challenges was to identify a location on Earth that resembled the environmental conditions on Mars as a site for the habitat. Haughton Crater on Devon Island, Nunavut, Canada was selected.

The Mars-like geologic features and extreme cold temperatures make Haughton Crater a good Earth locale to test an experimental facility for an extended human mission to Mars. For more information on Haughton Crater and the habitat, visit the Mars Society web site (http://arctic.marssociety.org/devon.html).

### *The Problem*

By the time you complete the activities in this section, you will have identified and prioritized several factors needed to produce a habitable climate. These preliminary ideas can be applied to the Mars Society project to help design and construct the Flashline Research Station.

Do you agree that Haughton Crater is the best Earth location for an experimental Mars human habitat? What geologic and atmospheric conditions exist on Devon Island that may have lead to the decision to construct the facility there?

If you were a researcher on the science and engineering team designing and constructing this facility, what conditions would you have to set to allow humans to adapt to this environment and live in the habitat. Quantify your responses to this question as best as you can.

What materials would you use to construct the habitat in order to compensate for the extreme temperature conditions? How would your design produce habitable conditions for researchers to spend long periods of time at the facility? What other mission considerations are there for human habitability?

# Activity A

## Modeling Hot and Cold Planets

### Overview

Studying why extreme temperature differences exist between Earth and other planets in our solar system most similar to our planet presents a unique challenge to scientists. How can they conduct experiments with these large planetary bodies to learn about how they work? Which variables are most important in controlling and altering temperature? How do these variables interact within the whole planetary system to produce either the habitable temperature of Earth or the inhospitable temperatures of Mars and Venus?

One approach to this study is to design and construct physical models that simulate specific physical or chemical processes. With these small-scale models, researchers can conduct experiments to learn about how a much larger system works.

Teams will design experiments to test any one of the factors identified in their Knowledge Map (created in a previous activity) to determine if that factor could be responsible for the magnitude of the temperature differences. You will be limited to using available supplies, therefore you may not be able to investigate all of the factors.

**Figure 2.2. Setup of the experiment.**

Each team should divide into two sub-teams. Each sub-team will be responsible for completing half of the experiment. One sub-team should try to produce the highest temperature possible (Venus-like conditions) and the other sub-team will try to produce the lowest temperature possible (Mars-like conditions).

One of the materials, a light source, should remain at a constant height throughout the experiment. Both parts of the experiment should be run simultaneously in order to save time.

When the investigation is complete, all teams will convene to discuss which of the variables has the greatest effect on the temperature and habitability of a planet's surface.

## Learning Objectives

- ✓ Design an experiment to answer a specific question and test a hypothesis.
- ✓ Differentiate independent and dependent variables.
- ✓ Evaluate the results and suggest modifications to an experiment.
- ✓ Prepare a synthesis of experimental results to prioritize a set of parameters.
- ✓ Explain a conceptual relationship among temperature, energy inputs, and surface features.
- ✓ Describe strengths and limitations of physical models.

## Relevance

People around the globe are concerned with current events and the impact these events have on their daily lives. They are also interested in how these current events will affect future lives and generations. This is especially true for events that impact upon our shared habitat, the Earth system. In order to make predictions about how such a complicated system may develop in the future, we have to develop models. Models enable us to improve what we know about the relative importance and interconnection of specific factors or variables, so that we can better understand the delicate balance that regulates Earth's habitable temperature.

# Modeling Hot and Cold Planets

## Materials

2 small plastic containers (to hold the models)
2 light sources (150 Watt light bulbs)
2 digital thermometers per team
Various colors of aquarium gravel
Various colors of modeling clay
Water
Sand
Rolls of cotton
Transparency sheets
Rolls of clear plastic wrap
Bag of aquarium moss

## Methods

### Preliminary Discussion and Planning

1. Examine your Knowledge Map (Topic 1, Activity A) and develop a hypothesis to describe the factor that has the greatest effect in producing a planet's habitable temperature.
2. Challenge: design a physical model of one hot and one cold planet each, using materials available to you in the classroom.
3. Competition: design an experiment that achieves the greatest temperature difference between these two physical models.
4. Organize into investigative teams of about five students and determine the role of each team member. Complete and submit the Investigation sheet: Team Members.

### Experimental Design

1. Prepare your team's research proposal by completing and submitting the Experimental Design Proposal.
2. Prepare the experimental plan by completing and submitting the Methodology for a Controlled Experiment.

### Experimentation and Observation

1. Set up the experiment based on your Experimental Design Proposal.
2. Each team should follow a common protocol by taking temperature measurements of their hot and cold planet model every minute for a 20 minute period.
3. Record your measurements on the Data Sheet: Modeling Hot and Cold Planets.

4. A second round of experiments may be conducted. After the results are analyzed and discussed and if the researchers determine that modifications can be made to their experiment to achieve a greater temperature difference between the two models, repeat the steps for data collection and analysis.

## Data Analysis, Comparisons, and Consensus

1. Review the data your team collected for both models.
2. Analyze the temperature data by completing the Experimental Results Data Sheet.
3. Coordinate your team's presentation to the class.
4. Contribute to the class discussion of results. Based on this discussion, fill in the Investigative Team Consensus and the Priority of Experimental Parameters.
5. Answer all the Questions at the conclusion of the experiments and data analysis. This is an individual assessment of what you learned in the modeling experiments. All responses should be shared among the team to gain a collective understanding of the experimental results of modeling hot and cold planets.
6. Read and discuss the Reference: Mathematical Models.

## Investigation Notebook

1. Investigation: Team Members
2. Investigation: Experimental Design Proposal
3. Investigation: Methodology for a Controlled Experiment
4. Data Sheet: Modeling Hot and Cold Planets
5. Data Sheet: Experimental Results
6. Data Sheet: Investigative Team Consensus
7. Data Sheet: Priority of Experimental Parameters
8. Questions: Modeling Hot and Cold Planets
9. Essay: Modeling Hot and Cold Planets

# Team Members

Before planning and carrying out your experiment, you must first decide who will serve each role on your research team. Look over the responsibilities listed below and decide who will take on each position:

## Lead Researcher _____

**Responsibilities:**

- Organize activities of your team.
- Make sure that all members are contributing productively.
- Criticize the results of your experiments.
- Make suggestions to improve your experimental procedure.
- Initiate the repetition of an experiment if necessary.
- Keep notes on the following:
    1. How could your experimental procedure be improved?
    2. What materials do you lack in order to make this a more effective experiment?

## Materials and Data Managers

| Hot Planet | Cold Planet |
|---|---|
| _____ | _____ |

**Responsibilities:**

- Acquire materials for setting up the experiment.
- Coordinate team effort to set up the experimental model.
- Keep organized records of all experimental measurements.
- Collect, organize, and return all equipment at the end of class period.
- Organize all written material for your group and submit at the end of the class period.

## Experimental Communication

| Hot Planet | Cold Planet |
|---|---|
| _____ | _____ |

**Responsibilities:**

- Carefully note all the steps of experimental procedures.
- Construct diagrams of the experimental set-up.
- Construct graphs of the experimental results.
- Coordinate the team presentation of the results and analysis.

# Experimental Design Proposal

Before getting into the details of your experiment, propose a hypothesis and realize the limitations of your experiment. Be sure to review your hypothesis and limitations with your instructor.

## Hypothesis

How do you expect changing your selected habitability factor to affect the surface temperature of your model systems? Your selected factor should be the variable you consider to have the greatest effect in producing a habitable temperature.

## Experimental Limitations

How do the materials used in this experiment differ from the objects they are simulating?

How does your energy source differ from the object that it simulates? Is it the only source of energy present?

## Experimental Expectations

How large a temperature difference are you expecting between your models?

# Methodology for a Controlled Experiment

Design an experiment to determine if the habitability factor you have selected could account for the magnitude of difference in the surface temperatures of a cold (Mars-like) and a hot (Venus-like) planet. Your group should be divided into two sub-teams. One team should model high temperature conditions, the other low temperature conditions. Discuss the questions on the next page before carrying out your experiment. Wait until your experiment is in progress to fill in your answers. Be sure to review your methodology with your instructor.

| **Laboratory Materials** | **Simulated Object** |
|---|---|
| Light source | Sun |
| Plastic cup | Planet |
| Gravel, water, clay, sand, other textured materials | Surface of the planet |
| **Additional Materials** | |
| Meter sticks, thermometers | |

## Experimental Procedure

Indicate the steps you plan to take in order to conduct your experiment.

## *Analysis of Experimental Variables*

**Variables**
List all the materials you can change during an experiment.

**Independent Variable**
Which variable can the experimenter purposely change?

**Dependent Variable**
Which variable will respond to the change in the independent variable?

**Experimental Controls**
Which factors will not change during the experiment?

# Modeling Hot and Cold Planets

Record your data (once per minute for 20 minutes) in the table below. Report the temperature at 20 minutes and your estimated final temperature. The columns under "Round Two" should only be used if researchers decide to modify their experiments and repeat the procedure.

| Time (minute) | Round One | | Round Two | |
|---|---|---|---|---|
| | Hot Planet | Cold Planet | Hot Planet | Cold Planet |
| 0 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| 11 | | | | |
| 12 | | | | |
| 13 | | | | |
| 14 | | | | |
| 15 | | | | |
| 16 | | | | |
| 17 | | | | |
| 18 | | | | |
| 19 | | | | |
| 20 | | | | |
| 21 | | | | |
| 22 | | | | |
| 23 | | | | |

**Table 2.1. Observed Temperatures of Modeled Hot and Cold Planets.**

# Experimental Results

Report your experimental results based on the data you collected for the hot and cold planet models. First, note the temperature conditions achieved by both models. Next, plot your data and extrapolate your final temperature for the two models. Compare these preliminary results and explain what you have learned about your original hypothesis.

**Independent Variable:** _____

**Dependent Variable:** _____

## High Surface Temperature Planet (Venus-like) Conditions

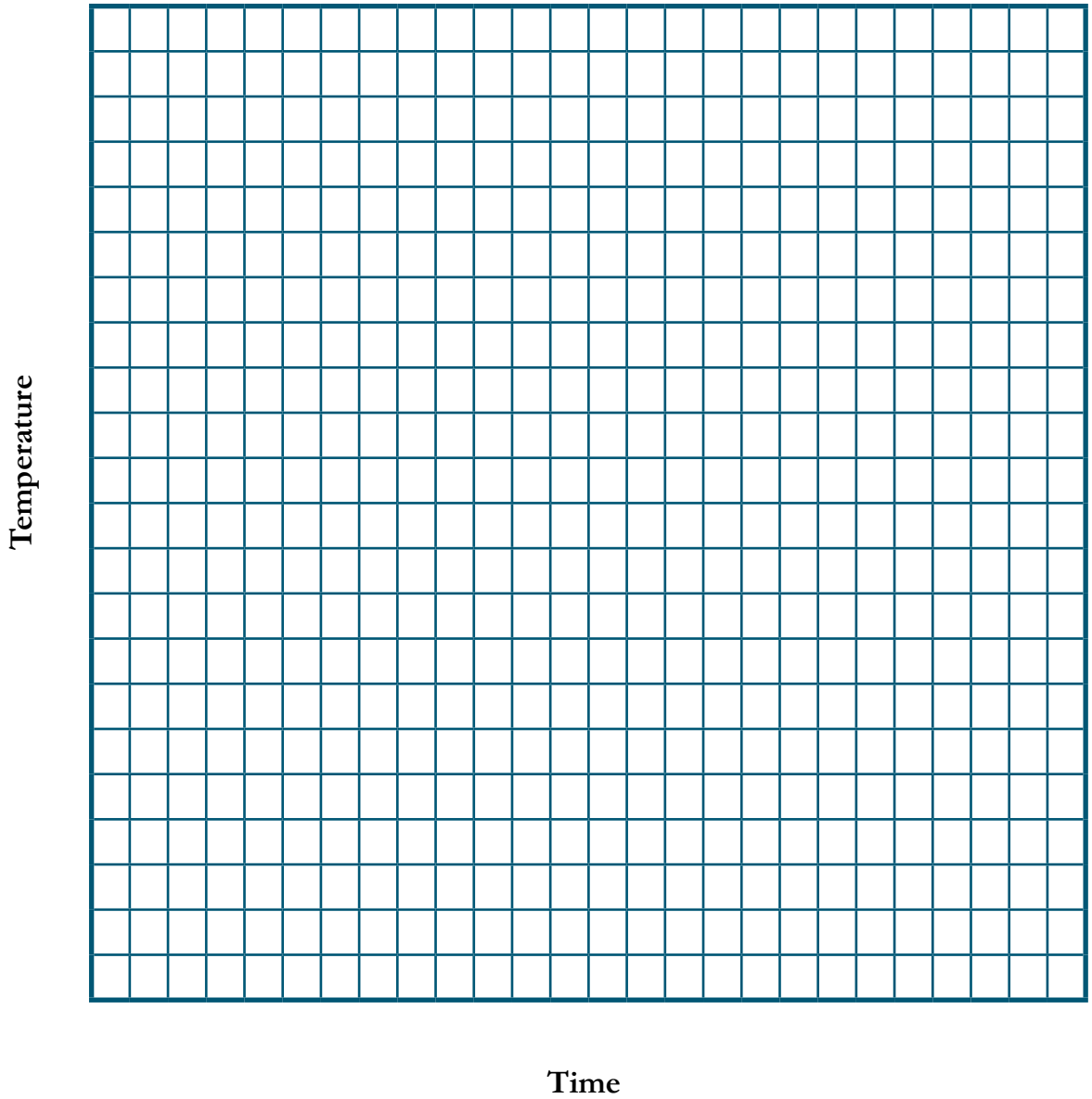
Describe your high temperature planet experimental conditions.

## Low Surface Temperature Planet (Mars-like) Conditions

Describe your low temperature planet experimental conditions.

## *Graph Data*

Graph your data and extrapolate your final temperature. Write a caption below your graph to describe how these conditions compared with your original hypothesis.




**Caption:**

If you were to repeat the experiment, what changes could you implement to make the magnitude of the difference in surface temperature closer to what you expected?

## Investigative Team Consensus

After all the teams complete the experiments and analyze their results, reconvene to discuss your findings. Try to determine the most effective way of changing the temperature of a planet. Students responsible for Experimental Communication will lead their team's presentation, summarizing their findings. These findings should be placed in a table on the board, similar to the table below. Fill in your copy of the table with results of the various teams as they are written on the board.

### Summary of all Teams' Results

| Team | Experimental Parameters | Hot Planet Temperature | Cold Planet Temperature | ΔT | ΔT/Time |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Table 2.2. All Teams' Results.**

# Priority of Experimental Parameters

The teams work together to list the various parameters used in order of their effectiveness in influencing the temperature of the model planet. Begin with the most effective and end with the least effective:

**Most Effective**

1.

2.

3.

4.

5.

**Least Effective**

6.

# Modeling Hot and Cold Planets

1. You have been asked to help design a house in the desert. What color window shades would provide the coolest temperatures inside the house?

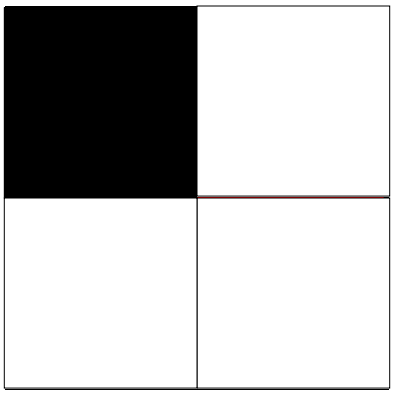
   a) white b) black
   c) green d) yellow

2. If we were able to remove all the clouds from Venus, how would the surface temperature of the planet change?

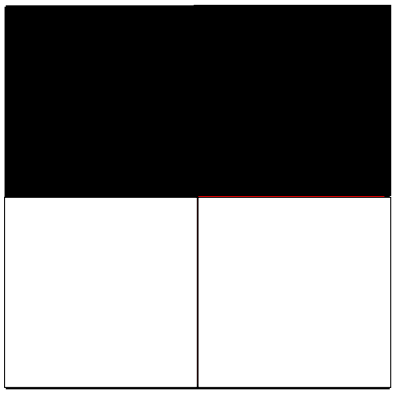
   a) It would increase
   b) it would decrease
   c) no change would be noticeable
   d) the temperatures would first increase and then return to the original temperature.

3. The following diagrams represent four parking lots in New York City. With all other factors being equal, which of these lots would have the highest daytime temperature?

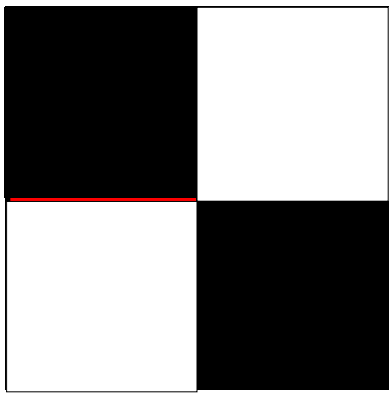
a)



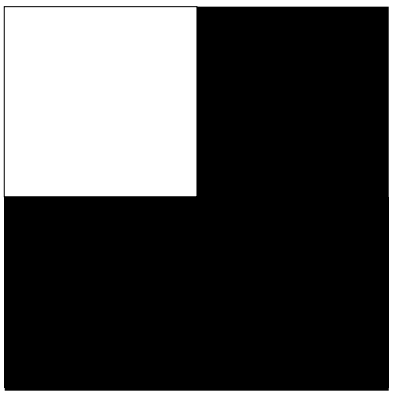
b)



c)



d)



4. A student wants to know how changing the material of a surface affects the temperature of the surface. She performs identical experiments, each time only changing the material. She uses sand, cement, glass, ice, polished aluminum, dry soil, and soil with grass. In each case, she places the surface 50 cm below a 250 Watt light source and measures the temperature of the surface every 30 seconds for 10 minutes. She records the results in a data table in her notebook.

   Which of these factors is the independent variable in her experiment?

   a) the light source
   b) the type of material
   c) the temperature
   d) the time taken

5. A student prepares four different models of planets using small plastic cups to represent the planets. The four models are constructed from different materials and placed at different distances from different light sources. The descriptions of the models appear in the table below.

   Which two models could be used to determine the effect of a single factor on the model temperature?

   a) I and II
   b) II and III
   c) III and IV
   d) I and III

| Model | Light Source | Distance | Material |
|---|---|---|---|
| I | 250 W | 20 cm | Red Clay |
| II | 100 W | 20 cm | Green Gravel |
| III | 250 W | 50 cm | Red Clay |
| IV | 100 W | 50 cm | Red Gravel |

# Modeling Hot and Cold Planets

During the planning of NASA's Apollo missions that took humans to the moon, the design engineers had to ensure that the habitability of the spacecraft would be maintained throughout the week-long mission. Based on the concepts you have learned in this activity, what would you expect were some of the features incorporated into the spacecraft's design so that a comfortable temperature was maintained? Explain each of your choices. If necessary, use an extra sheet of paper.

# Mathematical Models

Your attempts to create physical models of cold and warm planets were hampered by several problems and limitations. You used small plastic containers with only one or two types of surface. Measurements could only be taken for 20 minutes. The room was probably already warmed or cooled by a radiator or an air conditioner. You managed, however, to obtain results that appear qualitatively correct; brighter surfaces were generally colder and bringing the light source closer to the model increased the surface temperature.

This happens because physical phenomena follow basic laws of physics. If we now wanted to study those same phenomena and reduce the limitations of physical models, we could insert those basic laws of physics in the form of equations into a mathematical model and run it on a computer. This is exactly what you will do in the following activity – simulate the physical model experiments using a computer model. This first use of a computer model is just to whet your appetite. In the next topic you will follow a step-by-step process to build a computer model yourselves and to understand how such models can be used to study different systems.

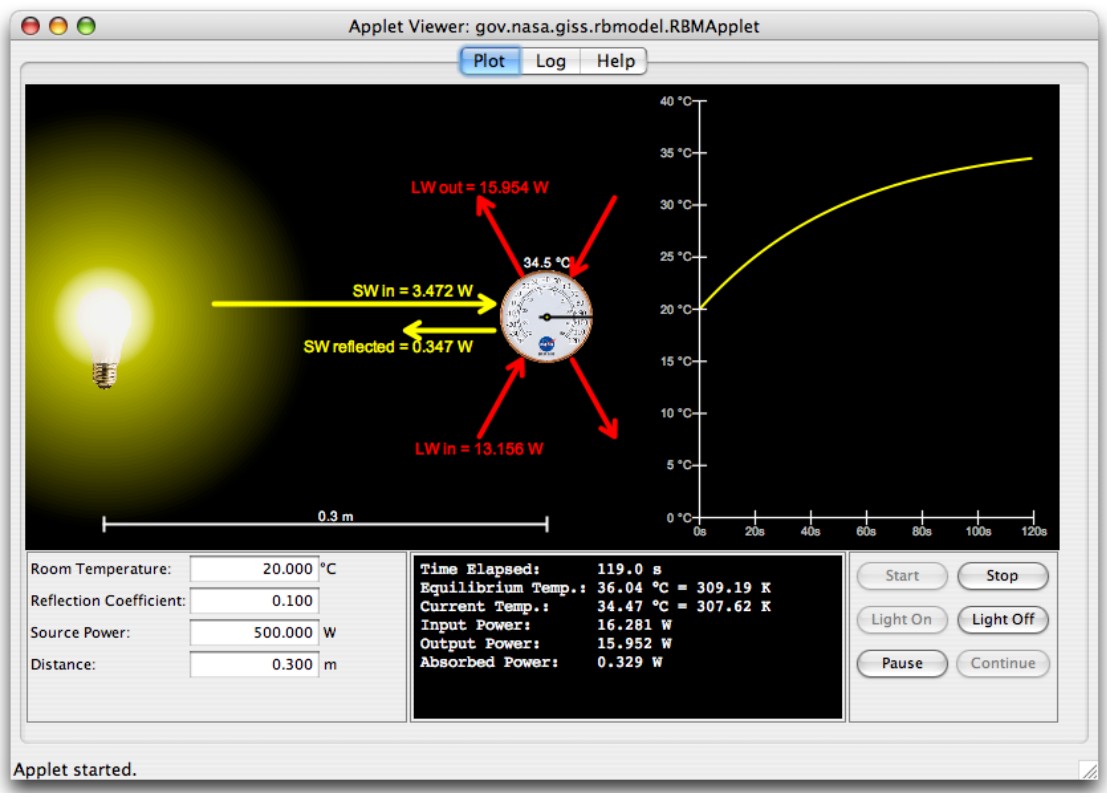



**Figure 2.3. An experiment in progress using the Local Radiation Balance Computer Model.**

# Activity B

## Experimenting with Computer Models

### Overview

The Local Radiation Balance Computer Model is available for your investigative team to run an experiment similar to the hot and cold planet physical model studies performed in the previous activity. Specifically, your team can run an experiment to see what happens when the room temperature is changed or when the "lights are kept on" for a continuous period of time. Several other experiments are possible with this computer model. By experimenting with the Local Radiation Balance Model, investigative teams will be able to assess how computer models can be used to understand factors that influence a planet's temperature.

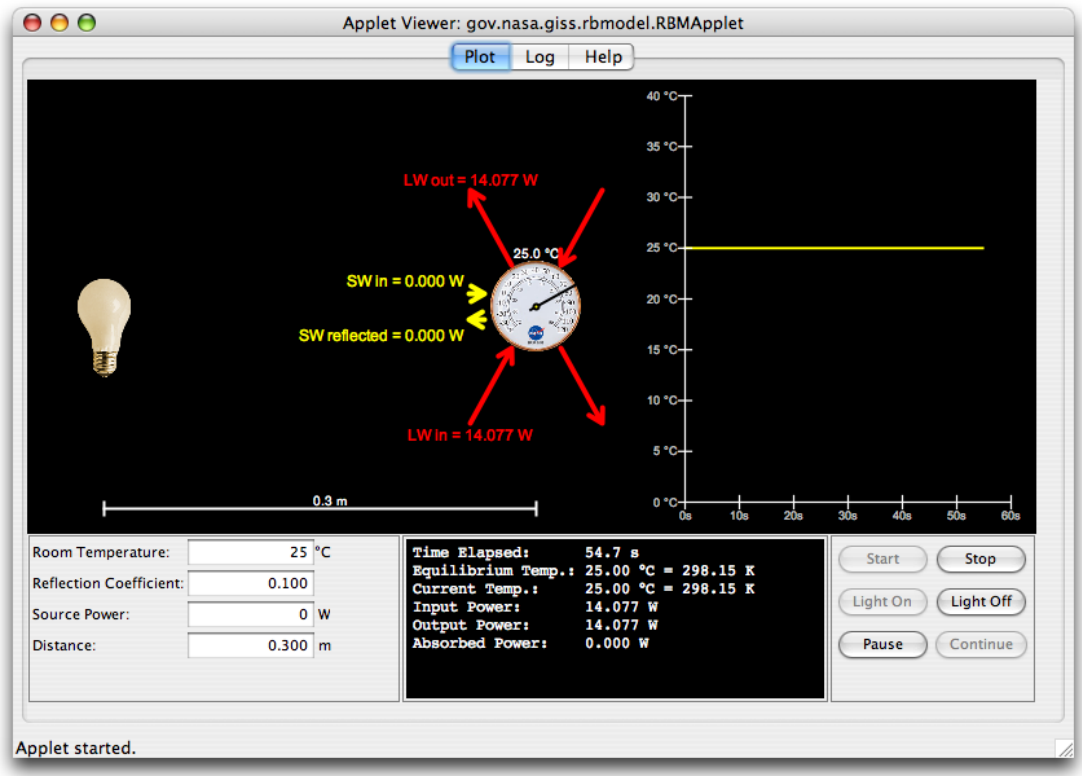



**Figure 2.4. Screen shot of the Local Radiation Balance Computer Model. No energy is emitted from the source, during this experimental run, resulting in a constant temperature for the objet.**

Work in teams of two or three students per computer to conduct two computer modeling experiments. By applying a methodology similar to the hot and cold planet physical models experiment, use the computer model to study the variables that influence temperature.

In the first experiment, the effect of distance from an energy source on temperature is investigated. A similar experiment can also be performed to investigate the effect of the power of the energy source on temperature.

In the second experiment, the effect of the surface features or reflectivity of an object on its temperature is studied.

Your aim in both experiments is to assess the importance of these variables on planetary temperature, as well as understand relationships between variables and the associated processes at work in the earth system.

## Learning Objectives

- ✓ Describe an equilibrium temperature.
- ✓ Identify the factors leading to an equilibrium temperature.
- ✓ Relate the temperature of an object to the energy it emits.
- ✓ Relate the temperature of an object to the reflectivity of its surface.
- ✓ Identify major energy inputs and outputs of a system.
- ✓ State and apply the Law of Conservation of Energy.
- ✓ Qualitatively relate 'distance from the source' to the 'energy incident upon an object.'
- ✓ Describe relative strengths and limitations of physical and computer models.

## Relevance

Mathematical computer models capable of simulating earth system processes enable researchers to conduct experiments that would be difficult, if not impossible, to implement on our planet. To understand the complex earth system, where changes occur due to so many natural and human processes, researchers must work with observations from the real world and results from computer modeling experiments. As research tools, mathematical models that run on computers give a researcher an opportunity to ask a range of "What if…" questions to try and discover how processes work in the earth system and how they may change in the future.

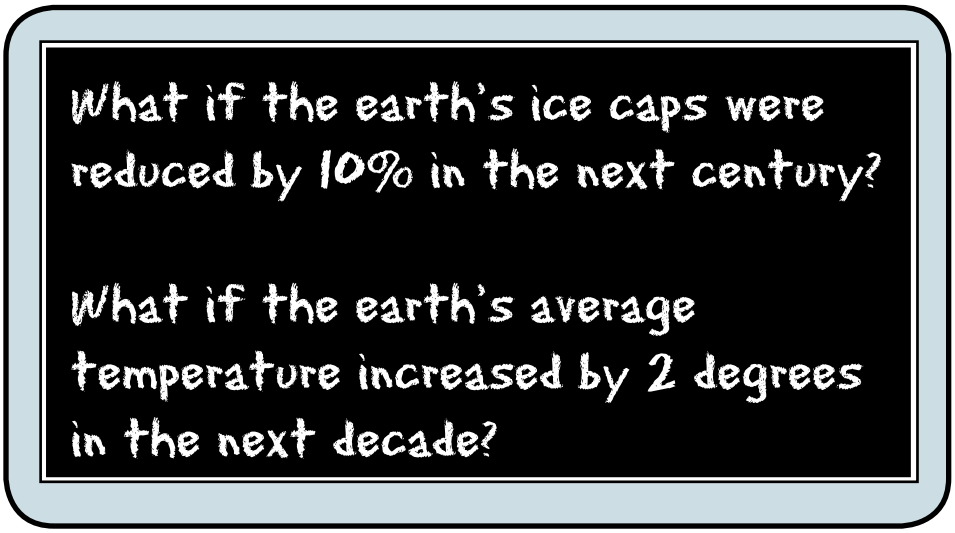



**Figure 2.5. Examples of "What if…" questions a researcher may ask to try and understand earth system processes.**

# Experimenting with Computer Models

## Materials

Computers to run the Radiation Balance Model. To use this model, you will need:

- ✓ A Windows (with any operating system including Win 95 or higher) or Apple PC.
- ✓ A web browser enabled with Java Version 1.3 or higher (Any Mac with OS X version 10.2 or better will include Java 1.3. Windows users may have to download and install the runtime version of Java at http://www.java.com/ )
- ✓ The courseware (a Java applet) loaded into your web browser: available at http://icp.giss.nasa.gov/education/modules/eccm/model/ – see Education Tools, Earth Climate Course Computer Models for Module 1.

## Methods

### Preliminary Discussion and Preparation

1. Pose several hypotheses for what will happen if you continue heating or supplying energy to the hot and cold planet models.
2. At the computer, review model features and experiments by reading the Reference: Local Radiation Balance Model User Guide. (*See page 45.*)

### Experimentation and Observation

1. Conduct Experiment 1. Complete Experiment 1 Data Sheet
2. Conduct Experiment 2. Complete Experiment 2 Data Sheet

### Data Analysis and Consensus

1. Discuss the results of your modeling experiments and prepare a presentation.
2. Share results as to what happened to the model's temperature.
3. What can be inferred about energy radiating to and from our planet from the fact that temperature reaches equilibrium? Which fundamental law is associated with this condition?
4. How did the albedo of the model's surface affect its equilibrium temperature?
5. What was learned about the relationship between distance and temperature?
6. What is meant by the phrase "Energy Balance"?
7. Assess what you learned by completing the investigation Questions.

**Investigation Notebook**

1. Data Sheets: Experiments 1 and 2.
2. Questions: Using Mathematical Computer Models
3. Essay: Topic 2: Preparing for Mars Living in an Arctic Outpost

# Introduction to the Local Radiation Balance Model

Study the radiation balance properties of an object exposed to a light source in a room by varying its albedo and distance with the Local Radiation Balance Computer Courseware Model.

The Local Radiation Balance Model simulates an experiment in which a object filled with some sort of material, and covered with a more or less reflecting surface, (supplying an albedo) is placed at a selected distance from an energy source. When the energy source is switched on, the student measures how the temperature of the object evolves with time. Parameters that can be adjusted are:

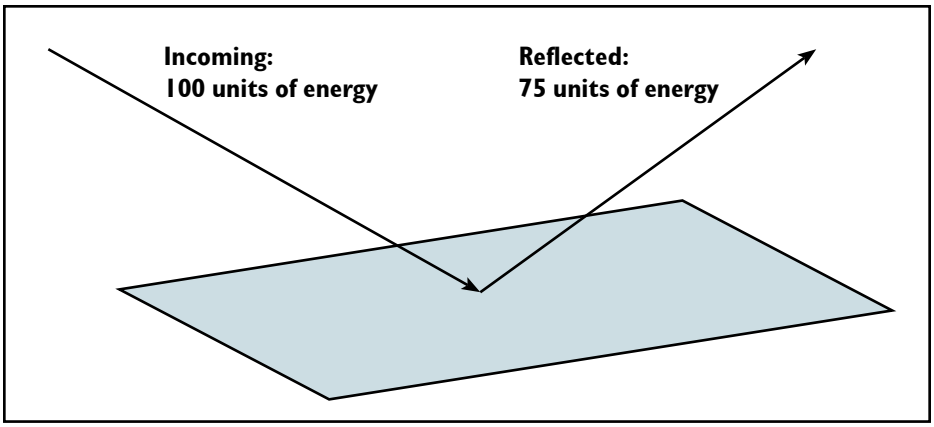



**Figure 2.6. Albedo (from Latin albus, meaning white) is a term used to describe the ability of a surface to reflect energy. An object that reflects none of the energy hitting it has an albedo of 0 (or 0%), and would appear black. An object that reflects all of the energy hitting it has an albedo of 1 (or 100%), and would appear white. In the diagram above, 75 of the 100 units of energy are reflected, therefore the surface of the object has an albedo of 0.75 (or 75%.)**

- The reflectivity (albedo) of the surface
- The distance between the energy source and the object
- The power of the energy source
- The ambient (or surrounding) temperature

## Experiments

Three experiments can be performed using this computer model:

1. A quantitative study of the relationship between equilibrium temperature and the distance from the light source to the box, demonstrating the Inverse Square Law.
2. A quantitative study of the relationship between equilibrium temperature and the reflection coefficient (albedo) of the surface of the box.

# Local Radiation Balance Model User Guide

The Local Radiation Balance Model contains three pages (or screens), each of which is described below. Use this guide to familiarize yourself with the features of the model, and as a reference during experimentation. To view the model, you will need to use a Windows or Apple PC and a monitor with a minimum 640 x 480 resolution and 256 colors. The model is available on the web at http://icp.giss.nasa.gov/education/modules/eccm/model/

## Page 1

The first page of the model (The Plot Screen) is the page on which the experiments are performed and is shown in figure 2.7 below.

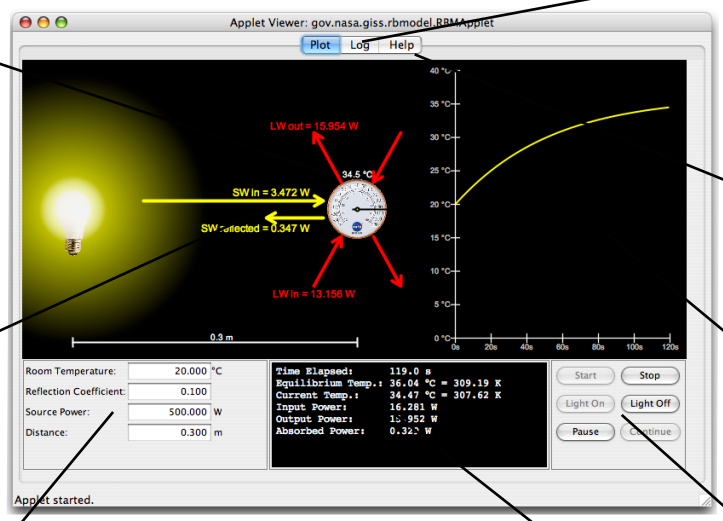



**Figure 2.7 Page 1 of the model.**

The red rays show the outgoing and incoming long wave energy between the object and the room.

The yellow rays indicate the short-wave energy that is received by and reflected by the object.

The room temperature, reflection coefficient, power of the source, and the distance are entered here..

See your experiment's log at any time by clicking on the Log button.

See a User Guide at anytime by clicking on the Help button.

Watch while a plot of your results is generated as the experiment proceeds.

Use these buttons to control the flow of your experiment.

The observation panel displays the variables as they change over time.

In the experimental control fields located in the lower left hand corner, the user is able to input the following values:

(1) the Room Temperature (in °C)
(2) the Reflection Coefficient (or albedo - a value between 0 and 1)
(3) the Power of the light source (in watts)
(4) the Distance between the source and the object. (in meters)

The user can then select whether the light source is on (for heating), or off (for cooling), and then start, stop or pause the experiment with the control buttons located in the lower right hand corner of this screen.

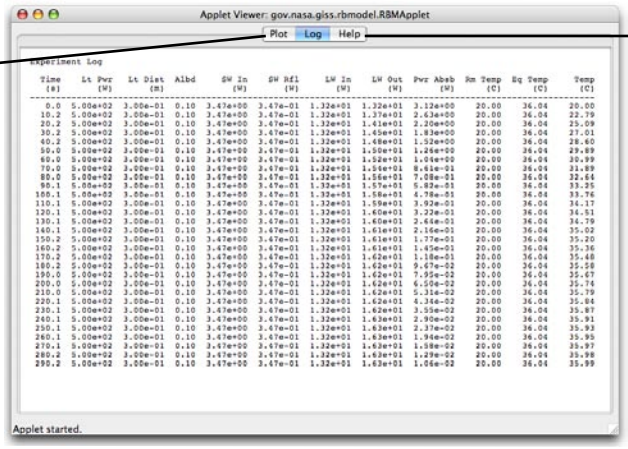
The resulting elapsed time, equilibrium temperature, the current temperature, and the input, output and absorbed powers of the object are displayed in the window located in the bottom center of this screen.

The user can select the other two pages (screens) by clicking on the "Log" and "Help" buttons at the top of this screen. Clicking on the "Plot" button will return the user to initial page.

## Page 2

After completing experiments, you have the choice of reviewing your log for completed sessions from your experiment. The log is erased every time you begin a new set of experiments.

The Plot button returns you to the first screen.




The Help button will bring up a User's Guide..

**Figure 2.9. Page 2 of the model.**

The data on this page can be highlighted and examined, but the present version of the applet does not allow the user to copy the data to the clipboard..

## Page 3

A brief User Guide to the radiation balance model appears on page three and can be accessed by clicking the "Help" button on any page.

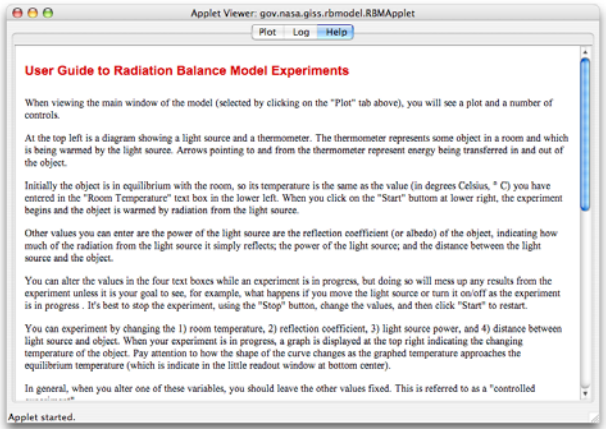



**Figure 2.10. Page 3 of the model.**

## Experiment 1

### *Study the relationship between equilibrium temperature and the distance from the light source to the box.*

1. Set room temperature to 20ºC and reflection coefficient to 0.
2. Make sure that the distance to light source is approximately 30 cm (0.30 m).
3. Click the "Light On" button.
4. Click the "Start" button.
5. Use the "Pause" button to suspend the experiment and look at the values of the various readings at any time. To unpause your experiment, click the "Continue" button.
6. Observe the graph that appears. Temperature (y-axis) is plotted versus Time (x-axis) since the light source was switched on. What happens as time progresses?

7. Observe the values for the different variables in the lower section of the screen. Has equilibrium temperature been reached? Compare the absorbed and outgoing power.

8. Continue timing until you think that equilibrium temperature has been achieved.
9. Click the "Stop" button.
10. Fill in the values for the four variables in the table below.
11. Repeat steps 3 through 10 with the distance set to approximately 60 cm and 90 cm. Do not change the room temperature or the reflection coefficient.
12. Note down values for the variables below.

| distance (cm) | outgoing energy/sec | absorbed energy/sec | present temperature | equilibrium temperature |
|---|---|---|---|---|
| 30 | | | | |
| 60 | | | | |
| 90 | | | | |

**Table 2.3. Results With Varying Distance and Room Temperature = 20°C.**

13. Now set room temperature to – 270ºC and the reflection coefficient to 0.
14. Repeat the experiment (steps 3 - 10) with the distance set to 30 cm, 60 cm, and 90 cm.
15. Note down the values for the variables in the table below.

| distance (cm) | outgoing energy/sec | absorbed energy/sec | present temperature | equilibrium temperature |
|---|---|---|---|---|
| 30 | | | | |
| 60 | | | | |
| 90 | | | | |

**Table 2.4. Results With Varying Distance and Room Temperature = – 270°C.**

16. What effect did increasing the distance have on equilibrium temperature? Explain.

17. Was the change in the equilibrium temperature (and absorbed energy) proportional to the change in distance? Elaborate.

18. Did the change in absorbed energy obey the Inverse Square Law? Why/Why not?.

19. What is the significance of setting the ambient temperature to – 270ºC?

20. Hypothesize as to how you might change this experiment to show the Inverse Square Law behavior.

21. In each case, how did the total energy arriving at the box compare with the energy emitted by it?

## Experiment 2

*Study the relationship between equilibrium temperature and the reflection coefficient of the surface of the box.*

1. Set the reflection coefficient to 0.
2. Set the room temperature to 20°C.
3. Make sure that the distance to light source is approximately 30 cm (0.30 m).
4. Click the "Light On" button.
5. Click the "Start" button.
6. You can use the "Pause" button to suspend suspend the experiment and look at the values of the various parameters at any time. To unpause your experiment, click the "Continue" button.
7. Observe the graph that appears. Temperature (y-axis) is plotted versus Time (x-axis) since the light source was switched on. What happens as time progresses?

8. Observe the values for the different variables in the lower section of the screen. Has equilibrium temperature been reached? Compare the absorbed and outgoing power.

9. Continue the run until you think that equilibrium temperature has been achieved.
10. Click the "Stop" button.
11. Fill in the values for the four variables in the table on the following page.
12. Repeat steps 2 through 10 with the reflection coefficient set to 0.2, 0.4, 0.6, and 0.8. Be careful not to change the position of the box, the room temperature, or the power of the source.
13. Note down values for the variables at the end of each run in the table on the following page.

| reflection coefficient | outgoing energy/sec | absorbed energy/sec | present temperature | equilibrium temperature |
|---|---|---|---|---|
| 0 | | | | |
| 0.2 | | | | |
| 0.4 | | | | |
| 0.6 | | | | |
| 0.8 | | | | |

**Table 2.5. Results With Varying Distance and Room Temperature = – 270°C.**

When you have completed the table above for the five different reflection coefficients and the corresponding values for other variables, answer the following questions on the basis of your results.

14. Did the equilibrium temperature increase or decrease as the coefficient increased? Why do you think this happens?

15. Was the power absorbed related directly to the reflection coefficient? Was the relationship linear or exponential between these two variables?

16. Was the equilibrium temperature simply related to the reflection coefficient? Was the relationship linear or exponential between these two variables?

17. Compare the response of the temperature to the reflection coefficient to the response of the power absorbed to the reflection coefficient.

18. What can you conclude from this experiment?

# Experimenting with Computer Models

1. How would increasing the amount of water in the physical model influence the time needed to reach thermal equilibrium?

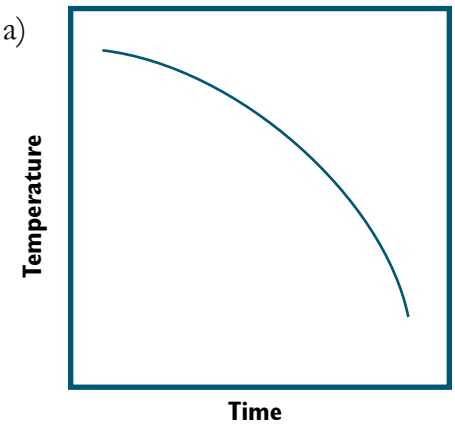
   a) It would take the same time.
   b) It would take longer.
   c) It would take shorter.
   d) Impossible to say without additional information.

2. Assume there are two planets with exactly the same characteristics, except that one is located far from the sun and the other close to the sun. The time for them to reach thermal equilibrium would:

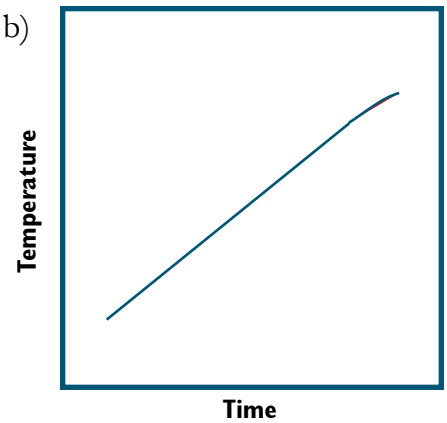
   a) be the same.
   b) be longer for the planet close to the sun.
   c) be longer for the planet far from the sun.
   d) depend on the distance of the closer planet.

3. Which of the following planets reaches thermal equilibrium the fastest?

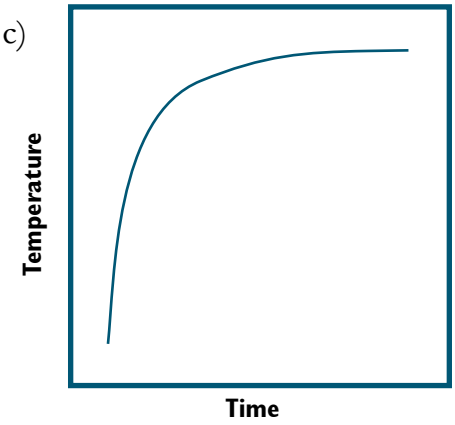
a)



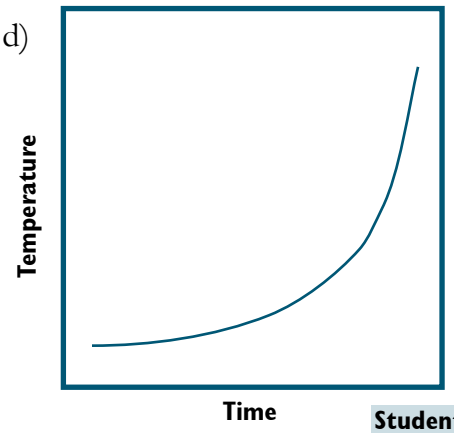

b)




c)




d)



# Activity C OPTIONAL

## Approximating the Average Surface Temperature of the Earth

### Overview

We have used a mathematical model, the Local Radiation Balance Model, to study some of the relationships that influence the temperature of an object when varying amounts of energy are supplied. This experiment simulated a planetary body and lead to assumptions about variables with the greatest effect on Earth's surface temperature. Scientists use far more complex computer models called General Circulation Models (GCMs) to simulate processes in a planetary system such as atmospheric circulation or wind patterns (e.g., the jet stream) and the ways solar radiation interacts with surface properties (e.g., the albedo or reflectivity of land and ocean). Just like the simple Local Radiation Balance Model, GCMs simulate earth processes using equations based on physical laws to determine a theoretical temperature for the surface of the earth.

What do you think is the earth's average surface temperature? How is it calculated? Since we have been talking about a global temperature for Earth, consider temperatures from all over the planet. How many temperatures do you need to use? This is a decision you must make as an investigator. You will need enough temperature values to get a relatively stable average. How many data elements or temperature values do you need to get a "good" average?

To understand the planetary temperature results produced by mathematical models, we need to ensure that we know (1) how to determine the actual average surface temperature of the earth, and (2) the value of that average. By computing the average, we can gain a scientific perspective on what happens in one part of the world and its impact on people in other regions and even throughout the world. This is why so many issues related to the environment are global concerns, and not only of interest to people locally or in a particular region.

Using an Internet web site, find temperatures from regions around the earth and calculate an average global temperature. A mathematical average will consider the sum of all data elements divided by the number of those elements. If you are using the Internet, one place to find this data is the USA Today website at www.usatoday.com/weather/forecast/wglobe.htm. Explore and record temperatures of locations around the world on the Data Sheet. Calculate an average global temperature using the USA Today web site or the Reference: Global Temperature Data.

### Learning Objectives

- ✓ Utilize a data source from the Internet.
- ✓ Determine the average temperature of the earth.
- ✓ Specify the characteristics of a sampling necessary to achieve an accurate average.

# Approximating the Average Surface Temperature of the Earth

## Materials

Computer with access to the Internet. If you do not have Internet access, use the Reference: Global Temperature Data.

## Methods

### Exploration and Data Collection

1. Either using the USA Today website: www.usatoday.com/weather/forecast/wglobe.htm, or the Reference: Global Temperature Data, explore temperatures in regions around the globe.
2. Record temperature data for a minimum of 20 sites around the world on the Data Sheet for this activity. Be sure that your data points are representative of the entire surface of the planet.

### Data Analysis, Comparisons and Consensus

1. Compare your results with other students in the class.
2. Answer the Questions for Activity C.

### Investigation Notebook

Data Sheet: Approximating the Average Surface Temperature of the Earth
Questions: Approximating the Average Surface Temperature of the Earth

# Approximating the Average Surface Temperature of the Earth

| | Region/City | Temperature |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |
| 11 | | |
| 12 | | |
| 13 | | |
| 14 | | |
| 15 | | |
| 16 | | |
| 17 | | |
| 18 | | |
| 19 | | |
| 20 | | |

**Table 2.6. Sampling of data points for the surface of the earth.**

Compute your average temperature global surface temperature:

# Global Temperature Data

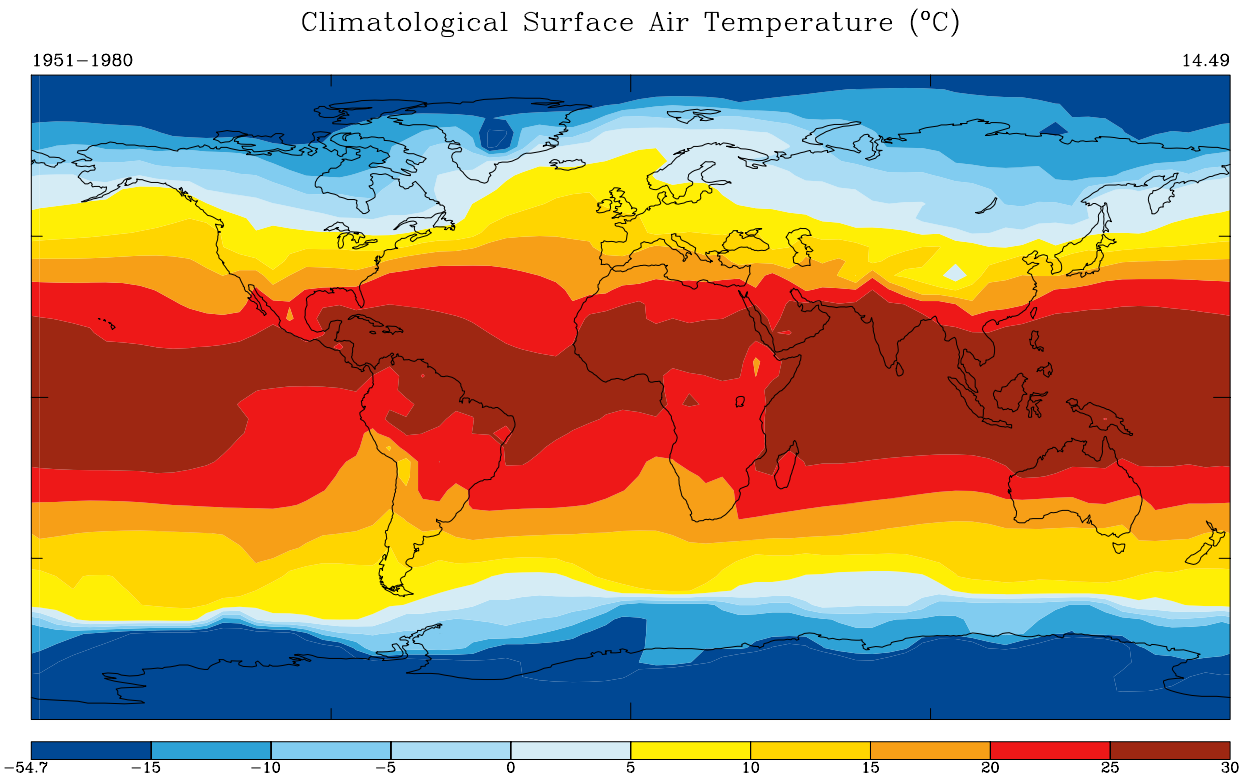



**Figure 2.11. Average global surface temperature calculated for a 30-year period (1951-1980). Data source: Legates.**

# Approximating the Average Surface Temperature of the Earth

1. How can you ensure that you get adequate representation of all temperatures on Earth to get a reasonable estimate of its average temperature?

2. How many temperatures would you like to have in order to determine your average?

3. Calculate the average for 5, 10, 15, 20, etc., of your temperatures.

   (a) What happens to the average as you increase your number of samples?

   (b) What happens when only temperatures over land are used?

4. The accepted value for the average surface temperature of the Earth is _____ . (Ask your instructor for this value). How does your average value compare to this accepted value?

# Preparing for Mars Living in an Arctic Outpost

Write a 300 word essay that responds to the questions in this topic's Real World Problem (refer to page 22). Justify your response with supportive evidence from the modeling investigations you conducted, as well as what you learned computing the average surface temperature of Earth.

Topic

# 3 Using Mathematical Models to Investigate Planetary Habitability


**Activity A** Finding a Mathematical Description of a Physical Relationship

**Activity B** Making a Simple Mathematical Model

**Activity C** The Role of Actual Data in Mathematical Models

# Considering a Real World Problem

## Deforestation and Urban Heat Islands

### The Problem

Earth's surface features are continually changing. In our planet's ancient past, natural events caused the global mean temperature to cool to such an extreme that ice and snow covered much of the earth's surface, producing several Ice Ages.

But today, there is another variable to consider as a forcing on the planetary landscape and habitability: human civilization.

Land is cleared for agricultural production and to raise cattle. Loggers cut down trees for commercial profit from products manufactured with wood. This process of deforestation is decreasing the world's forests.

**Figure 3.1. View of New York City. Produced by World Surveillance Inc. using satellite imagery, aerial photography, and computer enhancement. The image shows heat levels from very hot red to cool blue. (satellite.rsat.com/rsat/apps/uhi_app/uhi_app/html)**

Tropical forests are particularly impacted. Some reports estimate that these areas will disappear in 100 years if the current rate of deforestation continues (NASA, 1998). The Brazilian Congress is voting to clear 50% the Amazon forest for agriculture and cattle. They believe this plan will improve the country's poor economy and enhance personal economic prosperity of its citizens. What effects might deforestation have on Earth's global and local temperatures?

Another way humans are changing Earth's surface is by building structures on the landscape. In the 20th century, great cities have developed. Areas once covered with plants and trees are now sites of skyscrapers, buildings and roads. These large cities are associated with a phenomenon called *Urban Heat Islands*, where temperatures warm due to built-up environments. Why would temperatures increase as a city grows?

# Activity A

## Finding a Mathematical Description of a Physical Relationship

### Overview

Your investigations in the laboratory have shown you the general relationship that the farther away an object is from an energy source, the lower its temperature and the less the energy that reaches it. This qualitative description is useful if we want to know which of two objects will be hotter or colder depending upon their relative positions from the energy source. But what if we want a more specific answer? *How* hot or cold will an object be if placed at a specific distance from an energy source? Exactly *how much* energy reaches the object? To get answers we need a more *quantitative* description of the relationship between these factors. Only when we have an exact description of the relationship are we able to make quantitative predictions.

The purpose of this activity is to obtain data necessary to precisely describe the relationships between energy arriving at an object located at a certain distance from an energy source, and its resulting temperature. Solar cells will be used to produce voltage that is directly proportional to the intensity of a light source. A volt meter will be used to record this voltage output, effectively measuring the relative brightness of the light. When determining the temperature of the object, be sure to use identical models. Teams will perform two investigations:

**Experiment 1. Examine the intensity of light at different distances from the energy source.**
**Experiment 2. Examine the temperatures of an object at these various distances.**

Before beginning these experiments, determine team member roles and prepare an experimental proposal. The data collected will be analyzed to produce a mathematical description (an equation) that relates the factors. In a later activity, these mathematical descriptions will be used to create a mathematical model.

### Learning Objectives

- ✓ Make measurements with a volt meter.
- ✓ Create a graph using a spreadsheet.
- ✓ Determine the best fit line for data using a spreadsheet.
- ✓ Quantitatively relate distance from a source to energy incident on an object.
- ✓ Quantitatively relate temperature of an object to the distance from a energy source.
- ✓ Use the derived relationships to predict observed values.

## *Relevance*

Often the process or phenomena that the scientist tries to model in a laboratory is too complicated, expensive or hazardous to simulate with a physical model. Increasingly, scientists turn to mathematical models to perform these simulations. Such models are based on mathematical descriptions of known processes constrained by physical limits observed in nature. These models are increasingly important to researchers, hence you should become familiar with how they are developed and the means by which they can be useful tools.

# Finding a Mathematical Description of a Physical Relationship

## Materials

Light sources (150 watt light bulbs)
Support for light source
Solar cell/sunphotometers
Digital thermometers
1 volt meter
3 small plastic cups (to hold identical models)
Materials to make identical surfaces for each model
Computers loaded with Microsoft Excel software for the second part of this activity

## Methods

### Preliminary Discussion and Planning

1. Discuss: Modeling experiments designed to produce the greatest temperature difference between a hot and a cold planet.
2. Challenge: Design a physical model using the materials listed above to quantitatively determine the effect of distance from an energy source on the intensity of energy reaching that distance, and upon the temperature at that point.
3. Competition: Determine the mathematical relationships that best describe the effect you discover in step 2 above.
4. Organize into investigative teams of about five students and determine the role of each team member. Complete and submit the Investigation sheet: Team Members.

### Experimental Design

1. Prepare your team's research proposal by completing and submitting the Experimental Design Proposal.
2. Prepare the experimental plan by completing and submitting the Methodology for a Controlled Experiment.

### Experimentation and Observation

1. Set up the two experiments based on your proposal.
2. Each team will follow a common protocol by taking light intensity and temperature measurements at the same distances for at least seven different distances.
3. Data is recorded on the Data Sheet: Physical Model Experiments.
4. Complete the Data Sheet: Experimental Results.
5. Use a spreadsheet program on a computer to graph your results.

## Data Analysis, Comparisons and Consensus

1. Review the data collected by your team for both experiments.
2. Each sub-team should plot its own data and from that plot try to determine the mathematical relationship between the two variables.
3. Each sub-team should then use the spreadsheet program, Microsoft Excel, to re-plot its data, and then use the features of the spreadsheet to re-evaluate the mathematical relationship between their variables.
4. Complete the Data Sheet: Experimental Results.
5. Coordinate your team's presentation to the class.
6. Contribute to the class discussion of results.
7. Answer the questions at the conclusion of experiments and data analysis (pg. 76). This is an individual assessment of what you learned in the modeling experiments. All responses should be shared among the team members to gain a collective understanding of your results.

## Investigation Notebook

1. Investigation: Team Members
2. Investigation: Experimental Design Proposal
3. Investigation: Methodology for a Controlled Experiment
4. Data Sheet: Physical Model Experiments
5. Data Sheet: Experimental Results
6. Questions: Finding a Mathematical Description of a Physical Relationship

# Team Members

Before planning and carrying out your experiment, decide who will perform each research role. Review the responsibilities and select team member roles.

## Lead Researcher _____

**Responsibilities:**

- Organize activities of team.
- Ensure all members are contributing productively.
- Communicate with other groups to verify experimental procedures and results, and criticize the results of your experiments.
- Make suggestions to improve your experimental procedure.
- Initiate the repetition of an experiment if necessary.
- Keep notes on the following:
  1. How could your experimental procedure be improved?
  2. What materials do you lack in order to make this a more effective experiment?

## Materials and Data Managers

| Intensity of Light | Temperature of Model |
|---|---|
| _____ | _____ |

**Responsibilities:**

- Acquire materials for setting up experiment.
- Clear a sufficiently large workspace at a lab table.
- Keep organized records of all experimental measurements.
- Organize and return equipment at the end of class.
- Organize and submit the group's written material.

## Experimental Communications

| Intensity of Light | Temperature of Model |
|---|---|
| _____ | _____ |

**Responsibilities:**

- Carefully note all steps of the experimental procedures.
- Create diagrams of the experimental set-up.
- Create graphs of the experimental results.
- Coordinate the team presentation of the results and analysis.

# Experimental Design Proposal

To prepare for the experiment, start by proposing a hypothesis. Try to anticipate the limitations of your experiment. Review your hypothesis and limitations with your instructor.

## Hypothesis

How do you expect changing distance to affect the intensity of the light reaching a point at that distance?

How do you expect changing the distance will affect the surface temperature of your model?

## Experimental Limitations

How do the laboratory materials available for this experiment differ from the objects they are simulating?

## Experimental Expectations

Do you expect changing distance to have the same effect upon temperature and intensity of the light reaching a point?

# Methodology for a Controlled Experiment

Design two experiments to be performed by the sub-teams previously selected. The first team should investigate the relationship between distance from a light source and the intensity of light at that distance. The second experiment should investigate the relationship between the distance of an object from the light source and the temperature of the object at that point.

| **Laboratory Materials** | **Simulated Object** |
|---|---|
| Light source | Sun |
| Plastic cup | Planet |
| Gravel, water, clay, sand, other textured materials | Surface of the planet, e.g., continents, oceans |
| **Additional Materials** | |
| Meter sticks, thermometers, volt meters, and solar cells | |

Discuss the following questions before carrying out your experiment. Wait until your experiment is in progress to fill in your answers.

## Experimental Procedure

Indicate the steps you plan to take in order to conduct your experiment.

## *Analysis of Experimental Variables*

**Variables**
List all the quantities that could change during the experiment.

**Independent Variable**
Which variable can the experimenter purposely change?

**Dependent Variable**
Which variable will respond to change in the independent variable?

**Experimental Controls**
Which factors will not change during the experiment?

# Physical Model Experiments

Record your data at a minimum of seven different distances in table 3.1 below.

| Distance (cm) | Intensity Measurements (volts) | | | Temperature Measurements | |
|---|---|---|---|---|---|
| | Source On | Source Off | Distance Intensity | ºC | K |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Table 3.1. Data from Physical Model Experiments.**

To simplify your calculations and models in this activity, you can "normalize" obtained values using table 3.2 below. Normalizing requires that you select one of your values, make it your standard unit by assigning it a value of 1. This can be done by dividing that value by itself. To change all measurements to the same unit or scale, you simply divide each of the other values of the same variable by this standard value.

For example, if you had distances of 1 m, 4 m, 5 m, 10 m, 12 m, and 20 m, select any one of these values as your standard unit. For example, if you select 5 m, to normalize all these distances you would divide this and all other values by 5 m. This would give normalized distances of 0.2, 0.8, 1, 1.4, and 4 respectively. The first distance is 0.2 of the standard unit. In other words, it is 0.2 of the standard distance.

Take your third set of values from the table as your standard values. Divide each distance by this selected standard value. Record results in table 3.2 below. Also normalize observed intensity and the temperature in degrees Kelvin and record them in the table.

| **Normalized Distance** (Distance Units) | **Normalized Intensity** (Intensity Units) | **Normalized Temperature** (K) |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

**Table 3.2. Normalized Values from Observations.**

# Experimental Results

Based on the data collected for the effect of distance on the intensity of light and on the temperature, report your experimental results. Plot your data and draw a best-fit line or curve, whichever is appropriate, for the values. From the best-fit line or curve, develop a mathematical equation to describe that line or curve. Compare the results of your two experiments and explain how these preliminary results relate to your original hypothesis.

**Independent Variable:** _____

**Dependent Variable:** Intensity of light (volt meter reading) at a specific point.

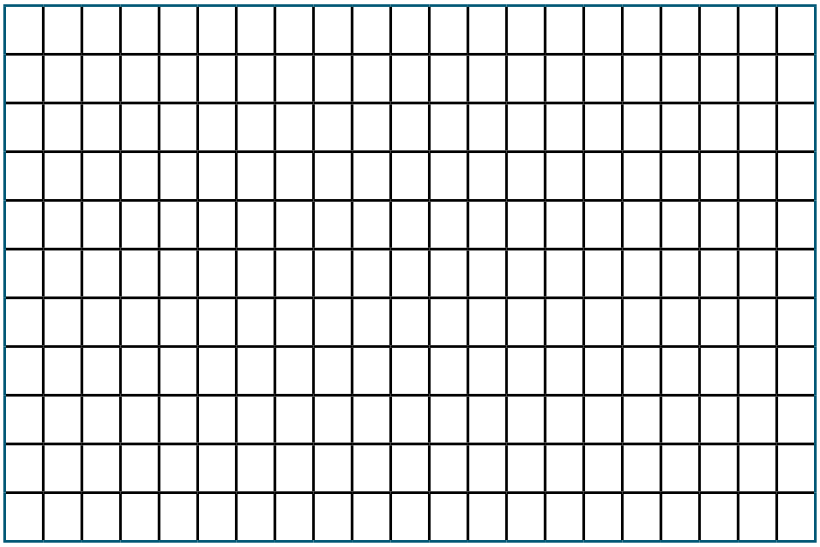
## Experiment 1 – Physical Model: Effect of Distance Upon Intensity of Light

### Experimental Conditions

Describe your experimental setup.

### Experimental Results

Label the axes below, plot data that you recorded in table 3.1 and describe the relationship you observe as best as you can.



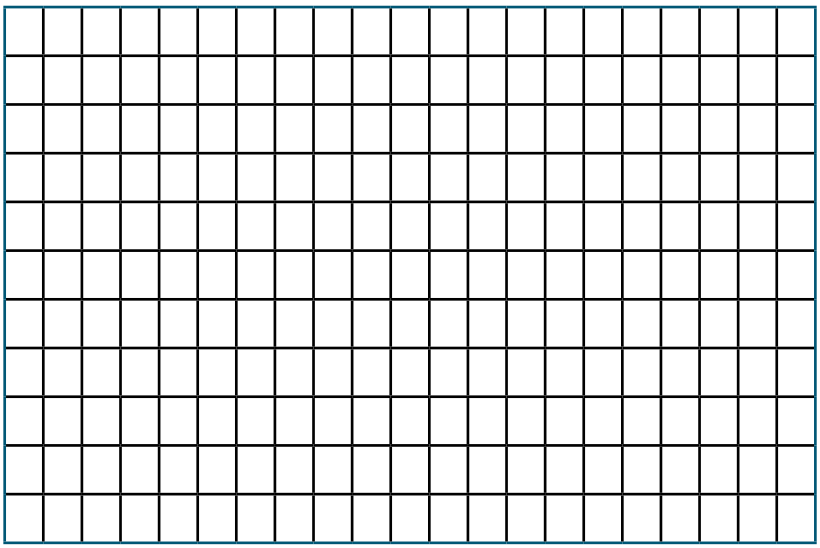
## Experiment 2 – Physical Model: Effect of Distance Upon Temperature

### Experimental Conditions

Describe your experimental setup.

### Experimental Results

Plot your data from table 3.1 and describe the relationship you observe as best as you can.



### Preliminary Results from Experiments 1 and 2

Compare the relationships between distance and the two conditions. Explain how these preliminary results bear upon your original hypothesis.

Can you quantitatively describe either of the relationships based upon the graphs you have drawn? Why or why not?

## *Deriving Quantitative Relationships with a Spreadsheet*

When a relationship between variables is not linear, it can be difficult to determine the exact mathematical relationship by simply examining data. A computer spreadsheet program can often help produce more quantitative results. It allows the user to easily manipulate, graph and analyze relationships using large amounts of numerical data. Use Microsoft Excel software to plot your data from the physical model experiment. Does this tool improve your ability to mathematically describe relationships among variables?

### Producing a Graph Using a Spreadsheet

- On a computer, start Excel. Have the data from your experiment ready.
- Using the normalized values from your table 3.2, enter information in columns beginning with cell A1. There should be 3 columns in your spreadsheet – distance, energy and temperature. Label the first cell in each column with a title for that column. If you are entering temperatures in Celsius, be sure to convert them to the Kelvin scale in the spreadsheet.

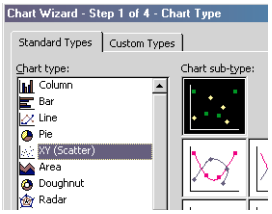
| | A | B | C |
|---|---|---|---|
| 1 | Distance | Energy | Temperature |
| 2 | | | |
| 3 | | | |
| 4 | | | |

- When the table is complete, begin analyzing the data. Sometimes, one can see relationships by examining numerical values. But it is usually easier to see them by plotting data points on a graph and studying the shape of the graph.
- Using the left button on the mouse, click on your title in the first cell of the first data column and hold down the mouse button. Drag the cursor to the last cell with data in this column and release the mouse button. All the data in the column should appear selected.
- Carefully, press and hold down the CTRL key on the keyboard. Then click on the title of the second data column you wish to plot and hold down the mouse button. With the CTRL key and the mouse button still pressed, drag the cursor down to the last cell with data in this column. Both columns should now appear selected.

| | A | B | C |
|---|---|---|---|
| 1 | Distance | Energy | Temperature |
| 2 | 2 | 2 | 1 |
| 3 | 2.4 | 3 | 2 |
| 4 | 2.5 | 4 | 2 |
| 5 | | | |

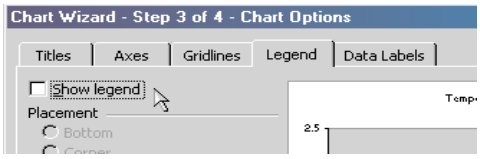
**Note: The data in the illustration above are examples. Use the data from your experiment to construct your own spreadsheet**

- On the toolbar located at the top of the spreadsheet, click on the Chart Wizard button – it is a multicolored icon that looks like a bar graph. Alternatively, you can click on the **Insert** menu, and then on **Chart**.
- A dialog box should appear to guide you through the graphing process. At the first step of the process, select **XY Scatter** as the chart type, choose the first sub type available (no line is drawn through the data.), and click on the **Next** button.



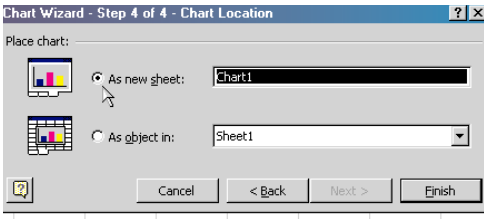

- At the second step, you will see a preview of your graph. Click **Next** to go to step 3.

- In step 3 - Chart Options, go to the **Legend** tab and remove the check mark on **Show legend**.




- Go to the **Titles** tab and fill in values for your graph title and the x and y axes. Be sure to include the units in axis titles. Click **Next**.

- In step 4 - Chart Location, select **As new sheet** and provide a title. For example: Energy vs. Distance. Click **Finish**. The completed graph appears on a new sheet by itself.




**Examine the graph that you have produced.**

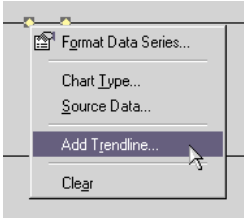
1. Describe the relationship between the two variables you have graphed.

2. What do you think is the most significant characteristic of the graph?

3. Does the graph agree with the graph you drew by hand?

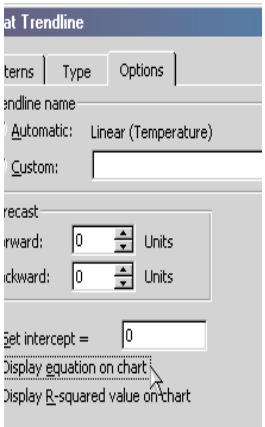
4. Does the graph ever touch the horizontal (distance) axis?

**Produce a trendline (the line that best fits your data) for your graph.**




- Using the right button on the mouse, click on any data point on the graph. On the menu that appears, select **Add Trendline…**
- Select the trendline shape that best resembles your plotted data. Ignore upwards and downwards extremes. Base your selection on the general shape. If the shape does not fit your data well, try others until you get what appears to be the best fit.

- After selecting your trendline, right click on the line. Select **Format Trendline...**, and then click on the **Options** tab and select **Display equation on chart**. Click on **OK**.
- The graph itself may obscure the equation of your trendline. You can click on and drag the equation to a clear area on the graph.




**Examine the trendline you have produced.**

1. How well does your trendline "fit" your data? Why do you think this is so?

2. What is the equation of your trendline?

3. How does this equation compare with the relationship you described earlier in Activity A of Topic 3?

4. How does this equation compare with your hand drawn graphical result?

5. Give a physical explanation of why this relationship exists in this form.

# Finding a Mathematical Description of a Physical Relationship

Answer the following questions on your own in complete sentences. You will need to use additional sheets of paper to answer all the questions completely.

1. How does the experiment you performed here differ from the hot and cold planets experiment performed in Topic 2?

2. Did the changing distance affect the temperature and the intensity of the light as you predicted? Explain.

3. What advantages did the spreadsheet program offer over analyzing your data by hand?

4. Do your final equations accurately describe the relationships between distance and temperature, and distance and intensity? Why or why not?

5. Are these two relationships sufficient to model planets in the solar system? Explain.

6. Two scientists perform different physical model experiments to investigate a particular phenomenon. They derive different equations to explain the phenomenon. How can they decide which equation is a better model?

7. An architect wants to know if the design for a 10-story building for downtown Los Angeles will be able to withstand a strong earthquake. What options are there for testing the design? What are the advantages and disadvantages of the options?

# Activity B

## Making a Simple Mathematical Model

### Overview

You will use your observed results for the relationships between distance and energy reaching an object and distance and temperature of an object to make your own simple mathematical model. Your model will allow you to change the luminosity of the light source and the distance to the light source. You can calculate the energy reaching the object and its black body temperature. Produce simulations of Earth, Venus and Mars to obtain their theoretical black body temperatures. Compare these results to the actual planetary temperature values. Upon completing the experiments, discuss the significance of this comparison and the role of models in science as well as possible improvements that could be made to your model.

Your investigations have shown a general relationship between the distance from the sun to a planet and the resulting planetary surface temperature – the farther away the planet, the lower its temperature. In Activity A, you derived a quantitative relationship between distance and intensity of energy. In Topic 2, you used the Radiation Balance Model to simulate the hot and cold planet experiment. How well did the model recreate these values and relationships? How can a mathematical computer model be created to model the features of a system?

A simple computer model will be created to determine the black body surface temperature of planets in the solar system. You will build this model on a computer using Microsoft Excel software. Mathematical equations will be used to modify given inputs to obtain desired results. The model inputs will be luminosity of the sun and the distance between the sun and a planet.

### Learning Objectives

- ✓ Make a spreadsheet model using Excel to determine the temperature of an object given its distance from an energy source.
- ✓ Compare theoretical and observed black body temperatures for a planet.
- ✓ State three advantages of using mathematical models.
- ✓ Describe three disadvantages of using mathematical models.

### Relevance

Even the most complicated mathematical models used by scientists today began with a few simple equations representing real world phenomena. You have seen how it is possible to derive a mathematical equation to describe relationships in experimental data. The next step is to use that relationship in a model to make predictions about real world situations. As more relationships are included in a model, along with inter-relationships and feedbacks, it becomes exceedingly complicated, but the basic equations remain at its core. Like scientists involved in climate modeling studies, you will use the relationships that you derived for your model of the solar system and evaluate the model's effectiveness.

# Making a Simple Mathematical Model

## Materials

A computer loaded with Microsoft Excel software, and the equations derived by you in this topic's Activity A.

## Methods

### Preliminary Discussion and Preparation

1. Discuss your expectations for your mathematical model with the class.
2. Familiarize yourself with the basic features of an Excel spreadsheet by reading and answering the questions in the Investigation section: Learning Excel – Applying Features of a Spreadsheet Program to Create a Simple Mathematical Model.

### Experimentation and Modeling

1. Follow the instructions to make your preliminary model and perform the experiments in the Investigation sheet: Creating a Simple Computer Model of a Planetary System.
2. Enter your model data on the Data Sheet: Making a Simple Mathematical Model.

### Data Analysis and Consensus

1. Compare the output of your model with the true values for Earth, Venus and Mars.
2. Evaluate the accuracy of your model.
3. Suggest ways of improving your model.
4. Discuss the advantages and disadvantages of using mathematical models.
5. To assess what you learned in the modeling experiments, complete the Investigation Questions.

### Investigation Notebook

1. Investigation: Learning Excel
2. Investigation: Creating a Simple Computer Model of a Planetary System
3. Data Sheet: Making a Simple Mathematical Model
4. Data Sheet: Experimental Results
5. Questions: Making a Simple Mathematical Model

# Learning Excel

## Applying the Features of a Spreadsheet Program to Create a Simple Mathematical Model

Start Excel on your computer. Once you begin the program, you will see a few blank worksheets that make up an Excel file, called a workbook, on the computer. Each sheet is divided into a series of lettered columns A, B, C, etc., and a series of numbered rows 1, 2, 3, etc. Each box, called a cell, in the spreadsheet is designated by its column and row identifier, such as A1, A5, B14 and so on. A cell can contain a value such as a word or a number, or it can contain a mathematical equation. If an equation is placed into a cell, the *result* of the equation is displayed in the cell and not the equation itself.

For example, a spreadsheet can be designed to determine the hypotenuse of a right triangle. The inputs would be the lengths of the two sides of the right triangle and the desired result would be the hypotenuse.

There are several ways to approach this problem. You could make a spreadsheet into which one set of values for the sides is entered and a single resulting hypotenuse is displayed. Or, a table of values can be entered for the lengths and a table of resulting hypotenuses will be created. The choice is yours.

In your Excel spreadsheet, enter the title for the first column: **Side A** in cell A1. In cell B1, enter the title: **Side B**. In cell C1, enter the title: **Hypotenuse**. In A2 and B2 you will eventually enter the values of the sides of your right triangle. In C2 you need to enter the equation that will determine the hypotenuse.

The Pythagorean theorem states that for a right triangle with sides a and b and hypotenuse c, $a^2 + b^2 = c^2$. Solving this for c yields:

Equation One: $c = \sqrt{(a^2 + b^2)}$

This equation must be entered into cell C2 in such a way that the spreadsheet can understand it. To raise a value to a power in a spreadsheet, the ^ symbol can be used (which is found on the number 6 key on the keyboard). $a^2$ would be written as a^2, $b^2$ as b^2, etc.

Remember that $\sqrt{a} = (a)^{1/2}$, therefore we can type the above equation into cell C2 as:

Equation Two: =(A2^2+B2^2)^0.5

Notice that for the sides we do not enter a^2, but rather A2^2 – referring to the location of the value and not the value itself. This way any value can be entered into cells A2 and B2 and

the resulting hypotenuse obtained in cell C2. After setting up the equation in your spreadsheet be sure to save the file on your computer.

Try entering some sample values for two sides of your right triangle. After constructing a model, it is usually a good idea to test it with known values to see if they give the expected results. A common right triangle is the 3, 4 and 5 triangle. Insert 3 and 4 as your sides and check the resulting hypotenuse. Your results should look similar to the diagram below. Test your spreadsheet with some other known right triangles.

| | A | B | C | D |
|---|---|---|---|---|
| 1 | Side A | Side B | Hypotenuse | |
| 2 | 3 | 4 | 5 | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |

What are the hypotenuses of the right triangles with the following sides?

Triangle One: Sides: 25, 15
Hypotenuse: _____

Triangle Two: Sides: 90, 120
Hypotenuse: _____

# Creating a Simple Computer Model of a Planetary System

## Modeling the Planets of the Solar System

Your task in this activity is to produce a mathematical model in a spreadsheet that can determine the black body surface temperatures of the planets in our solar system. Use the luminosity (brightness) of the sun (L), and the average distance (D) between the planet and the sun as your inputs.

Your spreadsheet model should be able to determine the average intensity of the energy reaching each square meter of the planet's surface (a value known as the *solar constant*, S) and the resulting black body temperature of the planet's surface. (A *black body* is a theoretical object that will absorb all the energy that it receives and then emit all that energy back to its surroundings.)

The two equations you derived in Activity A will come into play here. Use the relationship for the distance between the energy source and a point, and the amount of energy reaching that point, to determine the solar constant of a planet at a certain distance from the sun. Use the relationship between this distance or the amount of energy reaching that point and the surface temperature to determine the surface temperature of the same planet.

### Section 1. The Amount of Energy Reaching a Planet

The light from the sun radiates outwards in all directions, illuminating a sphere centered about the sun. The total luminosity of the sun, $L_{sun}$, is currently known to be $3.845 \times 10^{26}$ watts. Normalize this value and call it 1.00. The intensity of energy reaching the earth at the top of the atmosphere (the solar constant) has been measured to be 342 watts/meter$^2$. The earth is one astronomical unit from the sun. An astronomical unit (AU) is a convenient unit of distance when working with objects in orbit around the sun. 1 AU is the average distance between Earth and the sun.

Use these values and your distance relationship to write an equation for the spreadsheet that will enable you to determine the solar constant at any distance from a sun with a given luminosity, particularly at the positions of the nine planets in the solar system.

### Section 2. The Black Body Surface Temperature of the Planet

If the earth were a black body located in its current orbit around our sun, its surface temperature would be about 6ºC (279 K). Use this value and the relationship from Activity A that describes the effect of distance or the amount of incoming energy upon the temperature of an object. Write an equation for your spreadsheet that will determine the black body temperature of a planet at a specific distance from the sun.

## Section 3. Spreadsheet Model of the Solar System

Using the Reference: Planetary Distances from the Sun (on page 83) and the equations described in Sections 1 and 2 above, construct a spreadsheet model to determine the black body surface temperature of any planet in the solar system.

Your spreadsheet should allow you to input the following values:

1. the luminosity of the sun (L)
2. the distance of the planet from the sun (D).

The spreadsheet should then output the following values:

1. the solar constant (S) for that planet
2. the black body surface temperature

# Planetary Distances from the Sun

| Planet | Average Distance from the Sun (Astronomical Units) |
|---|---|
| Mercury | 0.3870 |
| Venus | 0.7233 |
| Earth | 1 |
| Mars | 1.5234 |
| Jupiter | 5.2033 |
| Saturn | 9.5376 |
| Uranus | 19.1914 |
| Neptune | 30.0693 |
| Pluto | 39.4818 |

**Table 3.3. Planetary distances from the sun expressed in astronomical units.**

# Making a Simple Mathematical Model

## Task 1

Using your spreadsheet model from Section 3 (above), determine the solar constant for each planet and the corresponding black body temperature of the planetary surface. Record results in table 3.4 below.

| Planet | D = Average Distance from the sun (AU) | S = Solar Constant (watts/meter$^2$) | Black Body Temperature | | |
|---|---|---|---|---|---|
| | | | (K) | (C) | (F) |
| Mercury | 0.3870 | | | | |
| Venus | 0.7233 | | | | |
| Earth | 1 | | | | |
| Mars | 1.5234 | | | | |

**Table 3.4. Predictions from Spreadsheet Model.**

## Task 2

Your instructor will provide you with the accepted values for these quantities. Fill in these values in the appropriate spaces in table 3.5 below.

| Planet | S = Solar Constant (watts/meter$^2$) | | % Error | Surface Temperature (ºC) | | % Error |
|---|---|---|---|---|---|---|
| | Model Value | Accepted Value | | Model Value | Accepted Value | |
| Mercury | | | | | | |
| Venus | | | | | | |
| Earth | | | | | | |
| Mars | | | | | | |

**Table 3.5. Comparing Model Results with True Values.**

## Experimental Results

1. How do the model and accepted values for the solar constant compare? Do you notice a general trend with these comparisons?

2. How do the model and accepted values for the surface temperature of the planets compare? Do you notice a general trend with these comparisons?

3. Did your model do a better job simulating the solar constant or the surface temperature? Why do you think this is so?

4. Which characteristic of your model would you most like to see improved? How would you go about making this improvement?

# Making a Simple Mathematical Model

Answer all of the following questions on your own and in complete sentences. Use additional sheets of paper if necessary.

1. What problems did you encounter while trying to construct your spreadsheet model of the solar system?

2. How did you overcome these problems?

3. Does your model produce results that agree with your expectations? Explain.

4. Do you think that modeling planets as black bodies is a useful technique? Explain what is good and bad about using such a model.

5. What suggestions can you make as to how to improve this model?

6. Weather predictions are done with mathematical models, and some predictors do better jobs than others. Give some possible reasons why the Acme Weather Company (*not the company's real name*) has the worst record for predicting the weather.

# Activity C

## The Role of Actual Data in Mathematical Models

### Overview

Models do not exist in a vacuum. They are based upon physical situations and require data as input in order to achieve desired output. The Excel spreadsheet model you built in the previous activity was based upon equations describing relationships observed in the real world. You determined these relationships by first making observations using physical models. You then provided data (luminosity of the sun and the distance of the planet from the sun) for the model to determine the surface temperature of a planet. The use of computer models allows us to extend our investigation beyond phenomena that can be modeled physically in the laboratory. Imagine trying to construct a physical model of the sun in order to better understand the mechanisms by which stars convert mass into energy. A mathematical representation is much easier to construct and infinitely safer to work with than a miniature sun.

How do we improve the mathematical descriptions used in our model? How do we obtain more data for fine tuning our model? This activity deals with these questions as we try to make our spreadsheet model better represent the characteristics of planets in our solar system.

You will use a more sophisticated spreadsheet model of a planet called *Global Equilibrium Energy Balance Interactive Tinker Toy* or GEEBITT. This model contains some of the modifications that you suggested would improve the spreadsheet models of your own design. GEEBITT takes into account the exact relationships between distance to the body at that point, as well as the reflectivity or albedo of a planet. The albedo of a planet can be input to GEEBITT along with the distance of the planet from the sun and the luminosity of the sun to determine the gray body surface temperature of the planet.

As a group, you will use NASA data from satellites to determine the average albedo of the earth. You will then use this albedo as an input to the GEEBITT Excel spreadsheet and determine a model value for the average surface temperature of the earth. Compare this theoretical value with the true value, and then perform similar comparisons for Mars and Venus, examples of cold and hot planets. Complete this activity by evaluating GEEBITT and determining further improvements that could be made to this mathematical model, if any.

### Learning Objectives

- ✓ Read and analyze an albedo map of the earth.
- ✓ Determine the average albedo of the earth.
- ✓ Become familiar with and utilize the GEEBITT spreadsheet model.
- ✓ Compare theoretical and observed gray body temperatures for a planet.
- ✓ Suggest further improvements to the spreadsheet model.

## *Relevance*

The quality of a model's output depends upon the accuracy of the mathematical descriptions used in the model, as well as the variety and accuracy of input data. If scientists are to make decisions and plan courses of action based upon the results of a model, they need to ensure that the model does the best job possible in simulating real world conditions. Real world data are a necessary component of this process and can be obtained from direct observations at the planet's surface or from observations via satellite. The data must be interpreted and converted into a usable form in order to be utilized by a model. This activity presents an example of such a process.

# The Role of Actual Data in Mathematical Models

## Materials

Computers loaded with Microsoft Excel software. A maximum of 2-3 students per computer is suggested.
To use this spreadsheet you will need:
A set of Reference images of the earth's albedo maps
A copy of the spreadsheet Albedo Calculator
A copy of spreadsheet mini-GEEBITT Version A
(Both these spreadsheets can be downloaded from: http://icp.giss.nasa.gov/education/)

## Methods

**Preliminary Discussion and Preparation**

1. Class discussion of the necessity of real data to serve as input into a model.
2. Review the concept of albedo with your classmates and instructor.
3. Interpret an albedo map presented by your instructor.

**Interpreting Data and Using the Albedo Calculator**

1. Determine the types and amounts of surfaces in the section of the earth assigned to your group.
2. Determine the approximate albedos of these sections.
3. Use the Albedo Calculator to determine the average albedo of this section of the earth.
4. Complete Experiment 1 – Part A: Determine the Average Albedo of the Earth.
5. Examine an albedo map of the same section of the earth that includes the influence of the atmosphere.
6. Use the Albedo Calculator to re-determine the average albedo of this section of the earth by including the atmospheric influence.
7. Complete Experiment 1 – Part B: Determine the Average Albedo of the Earth.

**Experiment with the Model**

1. Learn how to use the spreadsheet model of the solar system, GEEBITT. Read the GEEBITT User's Guide (see Appendix A).
2. Use GEEBITT and your average albedo to determine the surface temperature of the earth. Complete Experiment 2: Predicting Planetary Surface Temperatures.

## Data Analysis and Consensus

1. Compare the output of your model with true values for Earth, Venus and Mars.
2. Evaluate the accuracy of GEEBITT.
3. Suggest ways of improving GEEBITT.
4. To assess what you learned in the modeling experiments, complete the Investigation Questions.

## Investigation Notebook

1. Data Sheet: Experiment 1 – Part A: Determine the Average Albedo of the Earth
2. Data Sheet: Experiment 1 – Part B: Determine the Average Albedo of the Earth
3. Data Sheet: Experiment 2: Predicting Planetary Surface Temperatures
4. Questions: The Role of Actual Data in Mathematical Models
5. Essay: Considering a Real World Problem

# Experiment 1 - Part A: Determine the Average Albedo of the Earth

Your instructor will divide the class into groups of six students. Each group will use the following reference materials provided for Activity C to conduct this study:

1. A satellite image of the earth. (*Figure 3.5, on page 97 with a key on page 98.*)
2. A world map of the albedo of the earth (created from NASA and NOAA satellite data), divided into six equal sections. (*On page 99.*)
3. A key showing the numerical values of the albedos. (*At the bottom of the albedo map.*)

Each group will be assigned one of the six regions of the earth. As a group, you are to determine the average albedo of your section.

**Assigned section:** _____

## Tasks

1. Estimate the albedo of each type of surface identified in table 3.6 below.
2. Determine the number of grid boxes of each type of surface in your region and record these values in table 3.6.
3. Use these values in the Albedo Calculator spreadsheet to calculate the average albedo of your section.
4. Work with all the groups in your class to calculate an average albedo for Earth's surface.

| Region | Total | Water | Land: Vegetation | Land: Desert | Land: Snow & Ice |
|---|---|---|---|---|---|
| Number of Area Units | | | | | |
| Percent (%) Area | | | | | |
| Percent (%) Surface Reflectivity | | | | | |

**Table 3.6. Albedo for your group's region of the earth's surface.**

5. Enter the values of the estimated albedo of each type of surface and the percentage (in decimal format, 10% = 0.10) of that type of surface in your section of the earth into the Albedo Calculator spreadsheet. The spreadsheet will calculate the average albedo of your section. Record that result here:

**Average albedo of your region:** _____

6. Enter your average albedo as well as the average albedos of the other groups into table 3.7 below.
7. Determine the average albedo of earth from these values.

| Region | Average Albedo |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| Average | |

**Table 3.7. Average albedo of the earth.**

## *Analysis of Results*

1. Do you think the result obtained for the average albedo of the earth is a good approximation of this value? Why or why not?

2. What might be done to make this approximation accurate?

# Experiment 1 - Part B: Determine the Average Albedo of the Earth

Your instructor will now provide you with a map of the average albedo of the earth including the effects of its atmosphere. This map was created using NASA and NOAA satellite observations. (*Figure 3.8, Located on page 100.*)

## Tasks

1. Determine the average albedo of your global region, but this time calculate the value when clouds and other atmospheric effects are included in the model.
2. Enter these values into table 3.8 below.

| Region | Total | Water | Land: Vegetation | Land: Desert | Land: Snow & Ice |
|---|---|---|---|---|---|
| Number of Area Units | | | | | |
| Percent (%) Area | | | | | |
| Percent (%) Surface Reflectivity | | | | | |

**Table 3.8. Albedo including clouds and other atmospheric effects for your group's region of Earth's surface. Note: Percent surface reflectivity is adjusted for atmospheric effects.**

3. Enter the results of the other groups for their sections into table 3.9 below.
4. Use these results to determine the average albedo of the entire earth if atmospheric effects are included.
5. Enter the results from table 3.9 into the Albedo Calculator spreadsheet to produce a value for the average albedo of the earth including the effects of clouds and other atmospheric features. Record that value below:

**Average albedo of the earth including atmospheric effects:**

| Region | Average Albedo |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| Average | |

**Table 3.9. Average albedo of the earth including atmospheric effects.**

## Experiment 2: Predicting Planetary Surface Temperatures

Your instructor will tell you when to use the GEEBITT spreadsheet. Once you have opened the spreadsheet, do the following. If necessary, refer to the GEEBITT user's guide in Appendix A.

1. Enter the values for luminosity of the sun and the average distance between the earth and the sun that you used when making your own model.
2. Use the spreadsheet to determine the surface temperature of the earth with these values.
3. Enter this temperature in the appropriate space in table 3.10 below.
4. Enter the value for the average albedo of the earth (including cloud effects) that you determined in the previous experiment. Be sure to use the decimal value for the albedo.
5. Use the spreadsheet to determine the theoretical surface temperature of the earth. Write that value in data table 3.10 below as well.
6. Repeat this activity using the average albedos of Venus (0.76), Mars (0.25) and Mercury (0.11) to determine the theoretical surface temperatures of these planets.
7. Enter the values for theoretical surface temperatures of these planets with and without albedos in table 3.10.

| Planet | Average Surface Temperature Without Albedo | Average Surface Temperature With Albedo | Actual Average Surface Temperature |
|---|---|---|---|
| Earth | | | |
| Venus | | | |
| Mars | | | |
| Mercury | | | |

**Table 3.10. Theoretical average planetary surface temperatures.**

# Regional Effects of Human Development - Deforestation

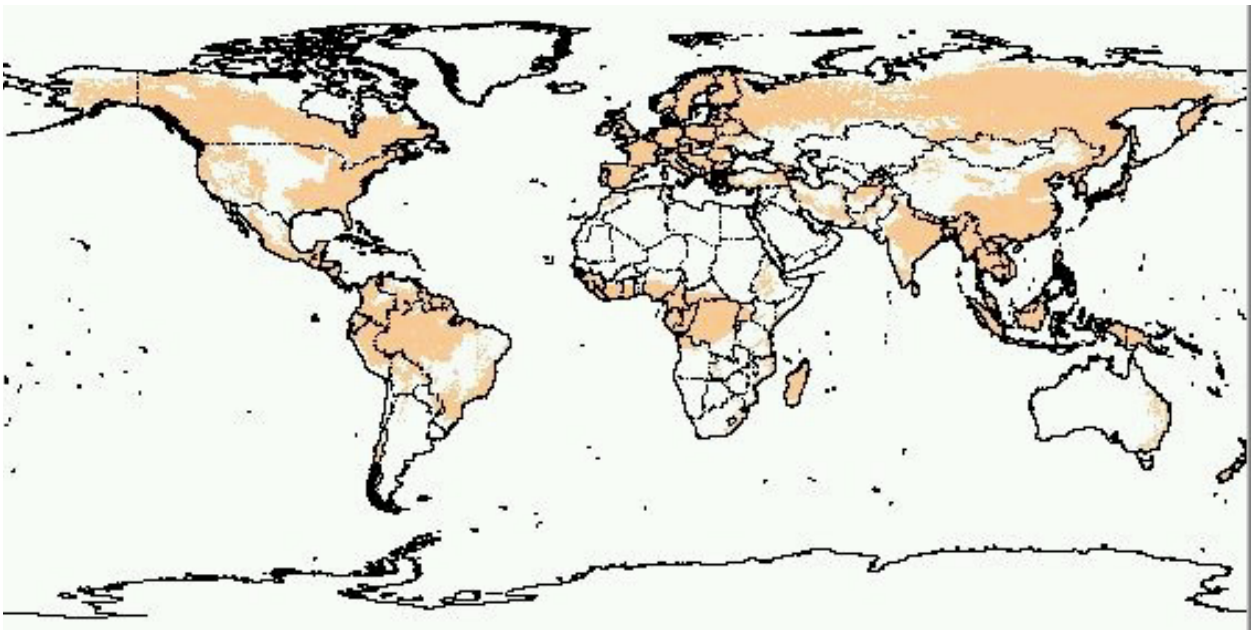


**Figure 3.2. Forests on the earth 8000 years ago are indicated by the shaded areas.**

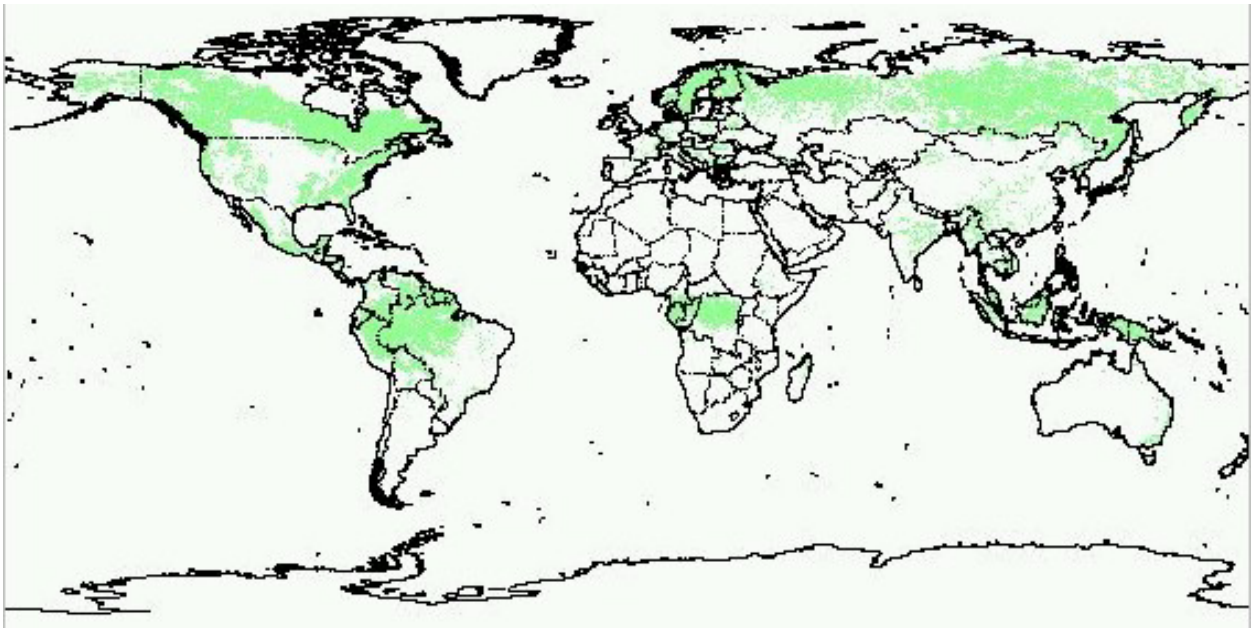


**Figure 3.3. Current forests on the earth are indicated by the shaded areas.**

# Regional Effects of Human Development - Urban Heat Islands

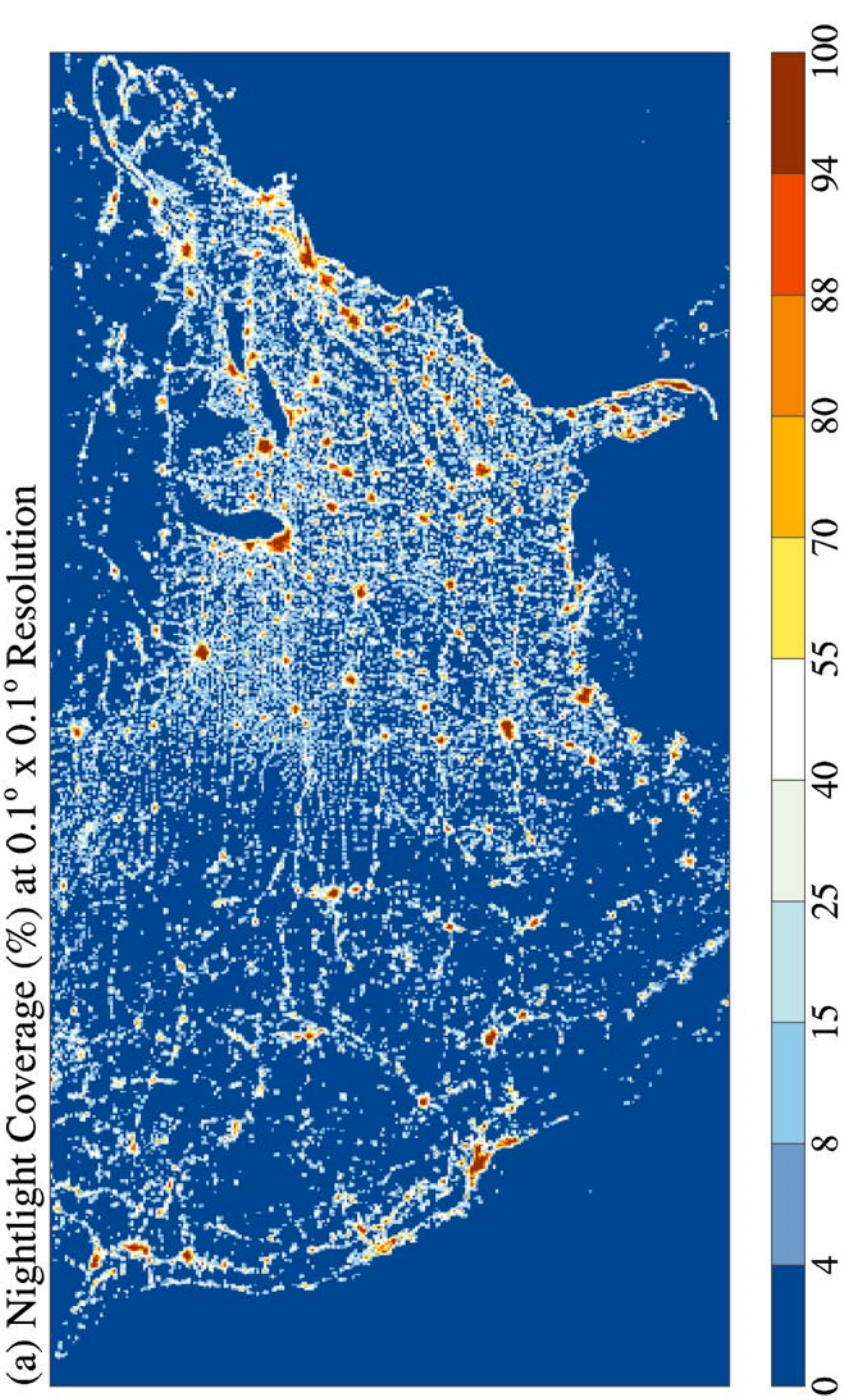



**Figure 3.4. Satellite view of night time city lights in the United States. The brighter areas can be related to population density and land surface development.**

# Map of Earth's Surface Coverage

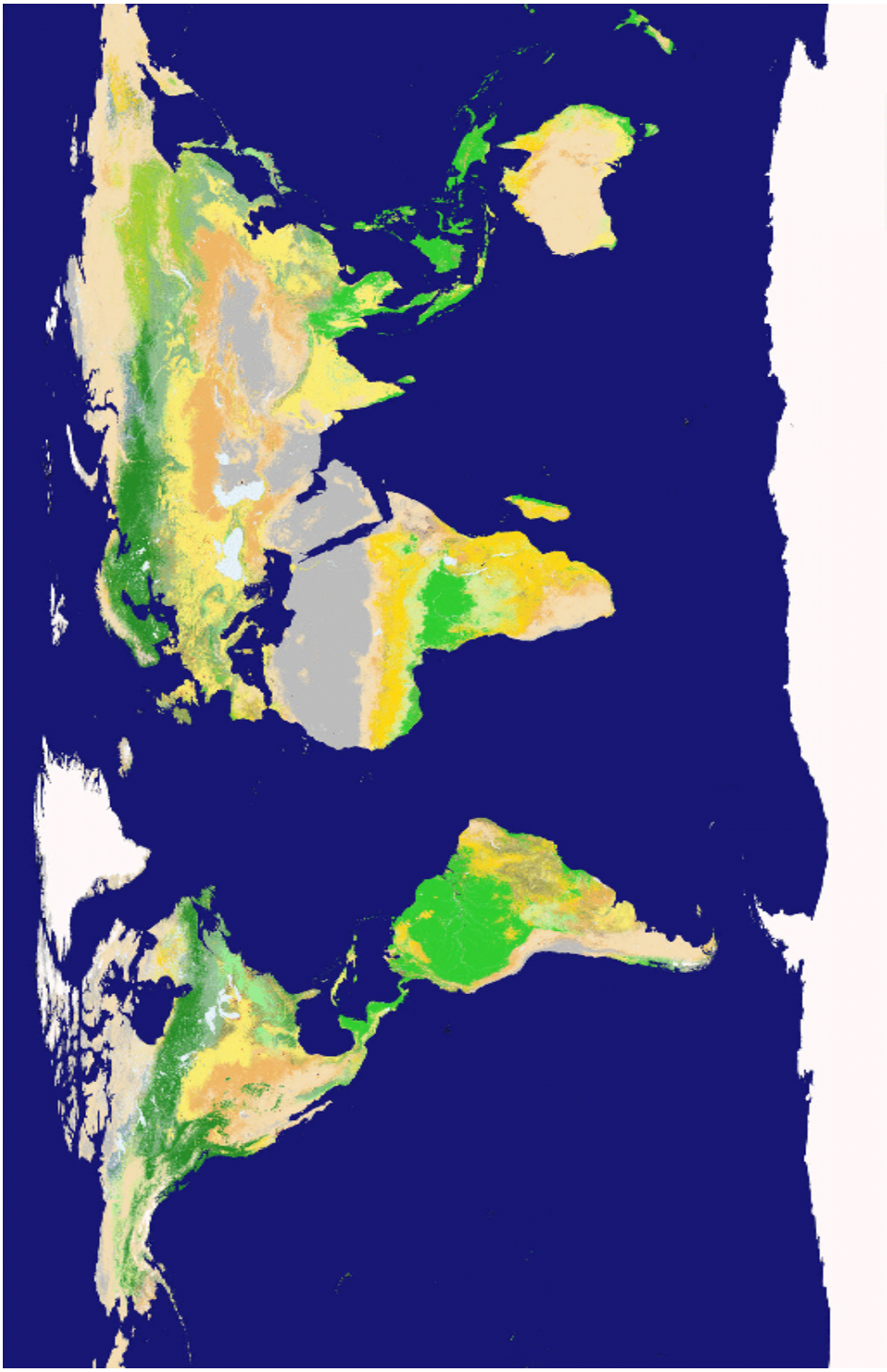


Figure 3.5. Map of Earth's Surface Coverage - October 2001. Data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Terra satellite. The land cover maps were developed at Boston University in Boston, Mass.

# Key for Earth's Surface Coverage Map

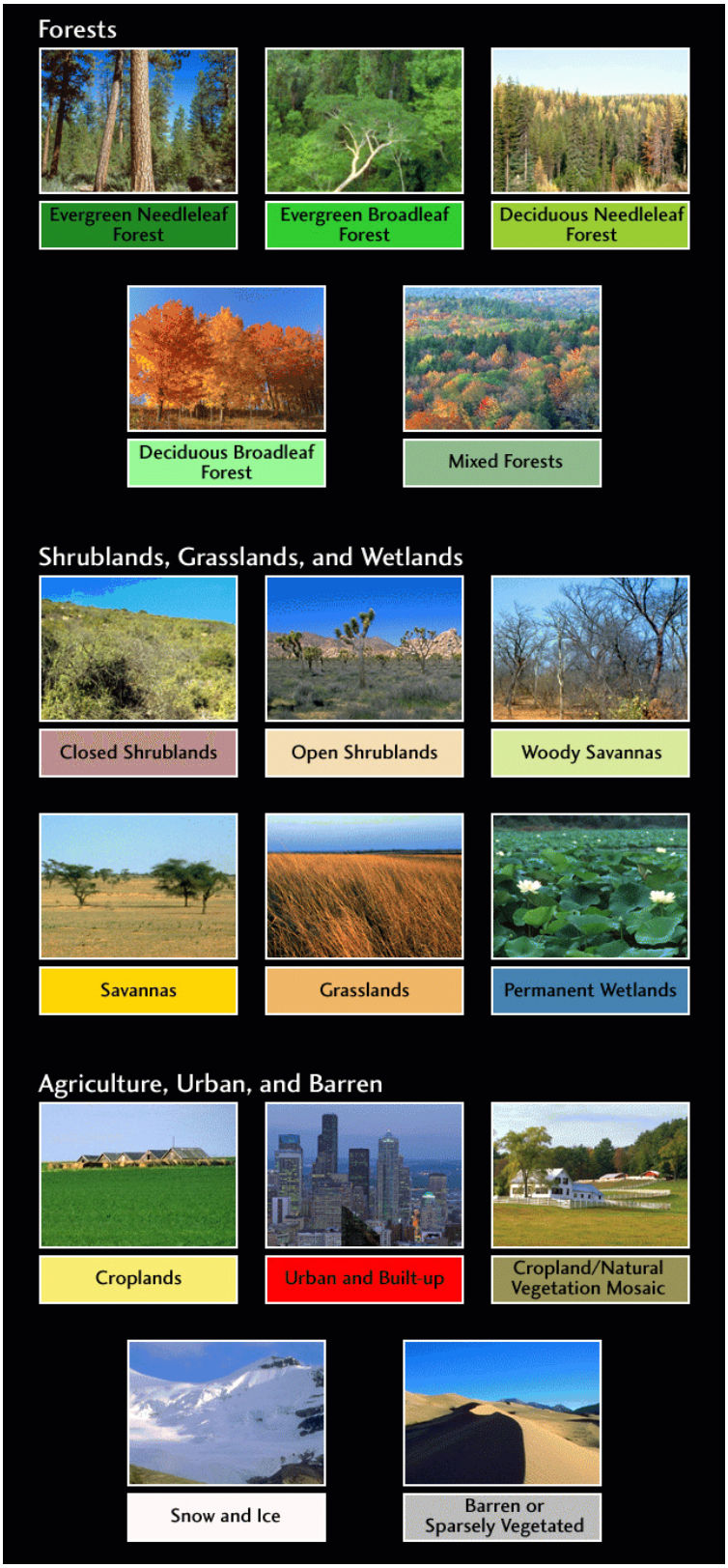



**Figure 3.6. Key for Map of Earth's Surface Usage - October 2001. The Key and the land cover maps were developed at Boston University in Boston, Mass. (For more information and maps, go to http://earthobservatory.nasa.gov/Newsroom/LCC/**

# Map of Earth's Albedo

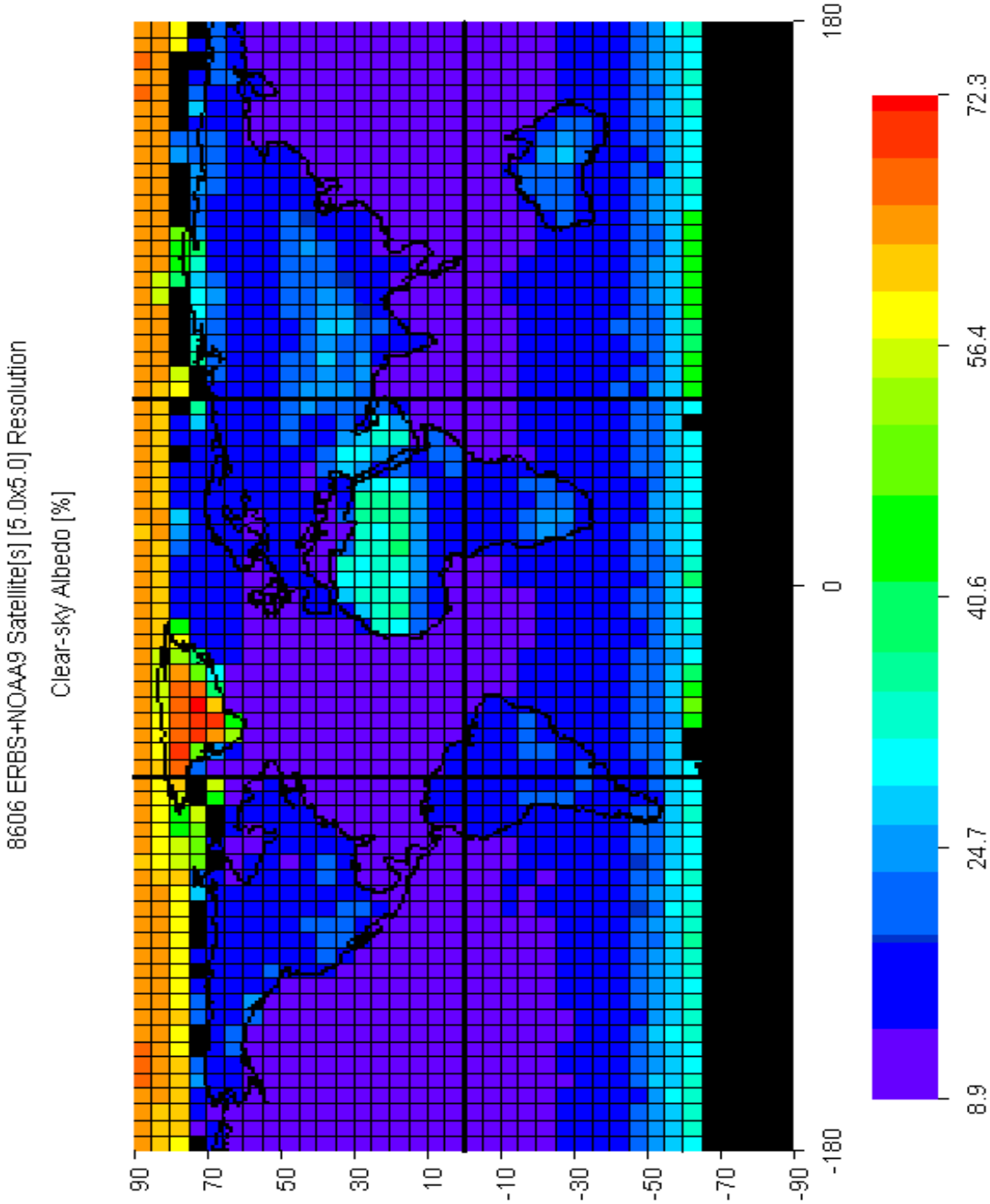



**Figure 3.7. Map of Earth's Albedo – June 1986. Data source: NASA Earth Radiation Budget Experiment and NOAA-9 Satellites.**

# Map of Earth's Albedo with Sky Effects in June 1986

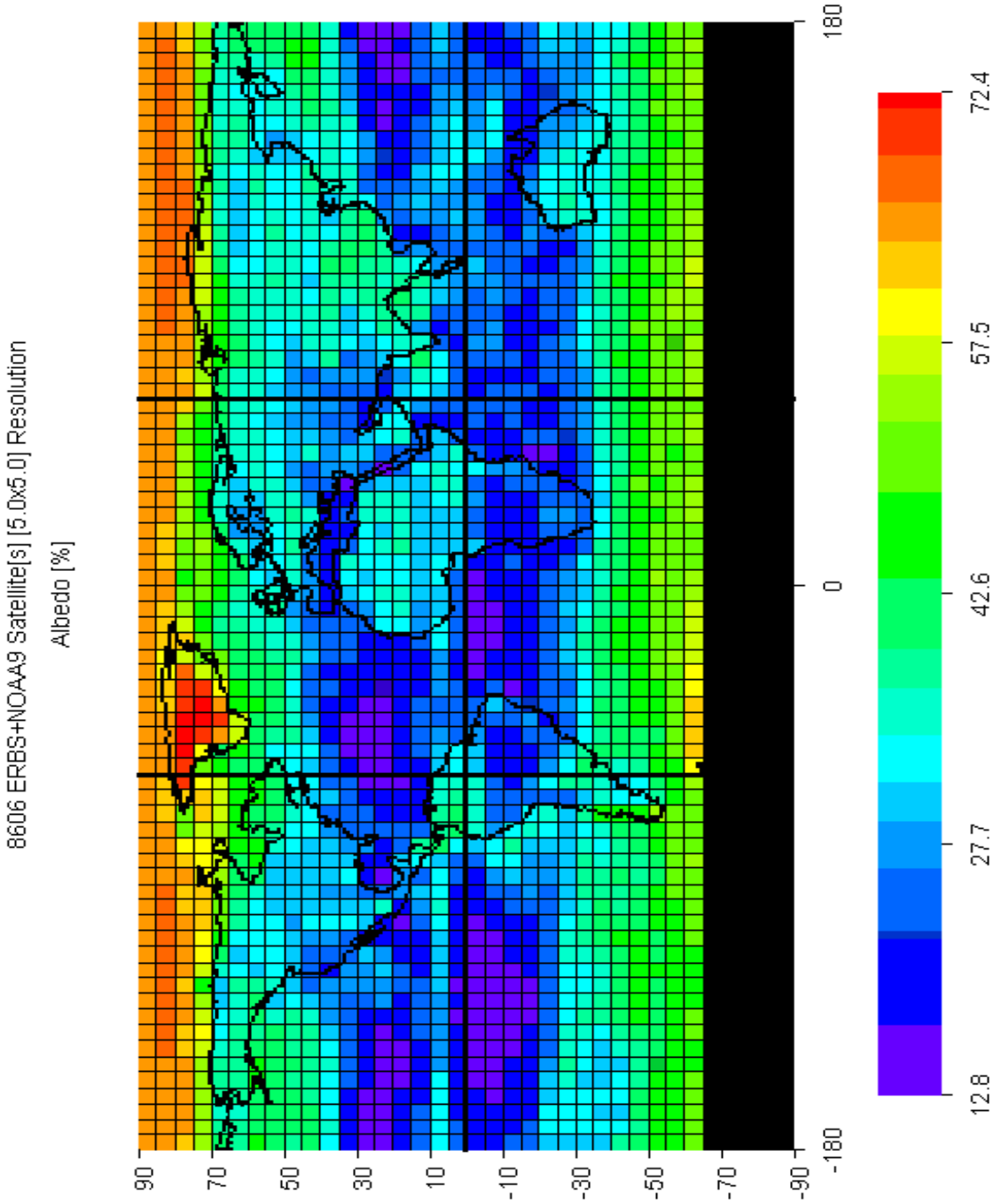



**Figure 3.8. Map of Earth's Albedo (Non-Clear Sky) – June 1986. Data source: NASA Earth Radiation Budget Experiment and NOAA-9 Satellites.**

# Map of Earth's Albedo with Clear Sky in January 1986

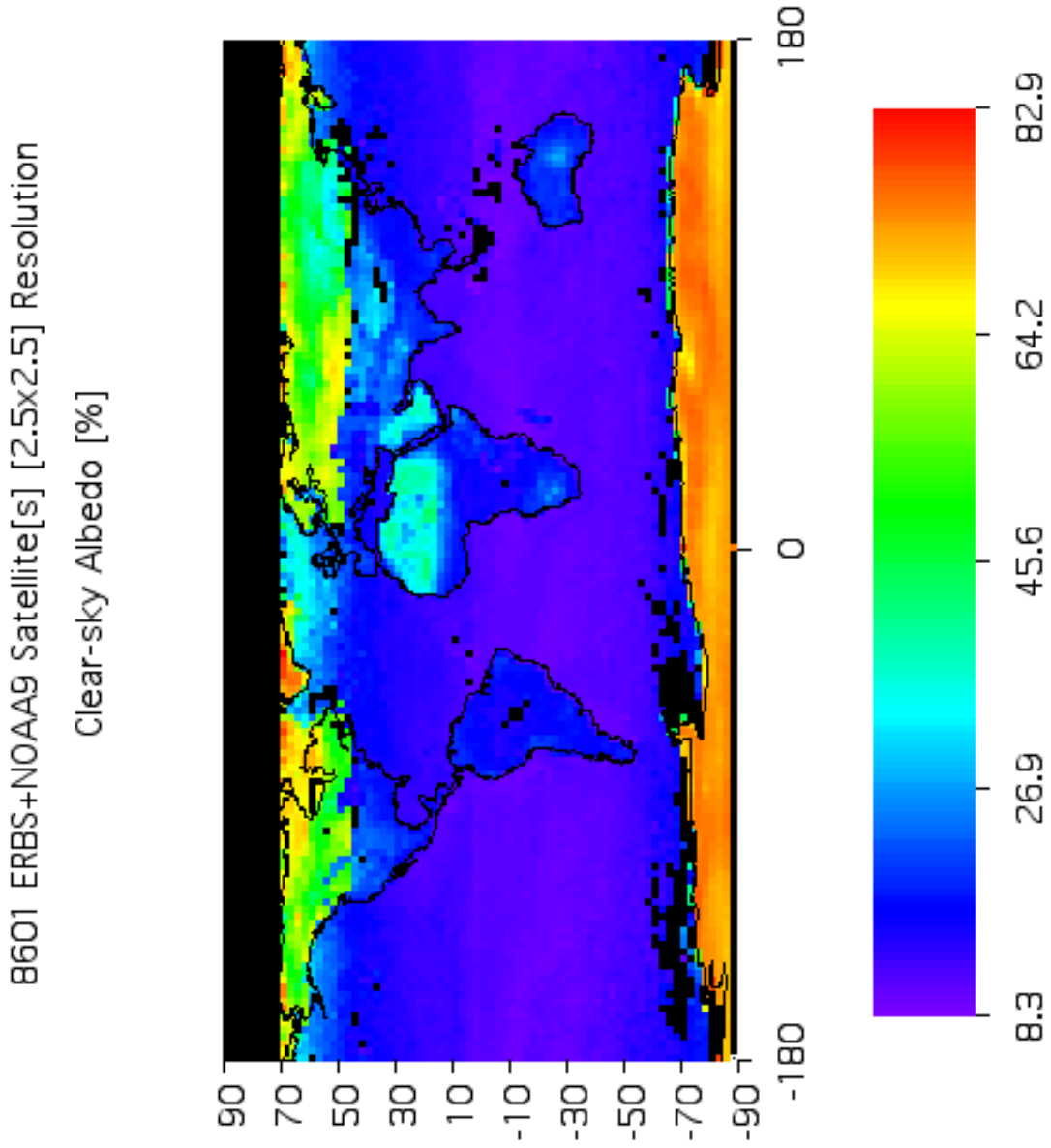



**Figure 3.9. Map of Earth's Clear-sky Albedo – January 1986. Data source: NASA Earth Radiation Budget Experiment and NOAA-9 Satellites.**

# Map of Earth's Albedo with Clear Sky in July 1986

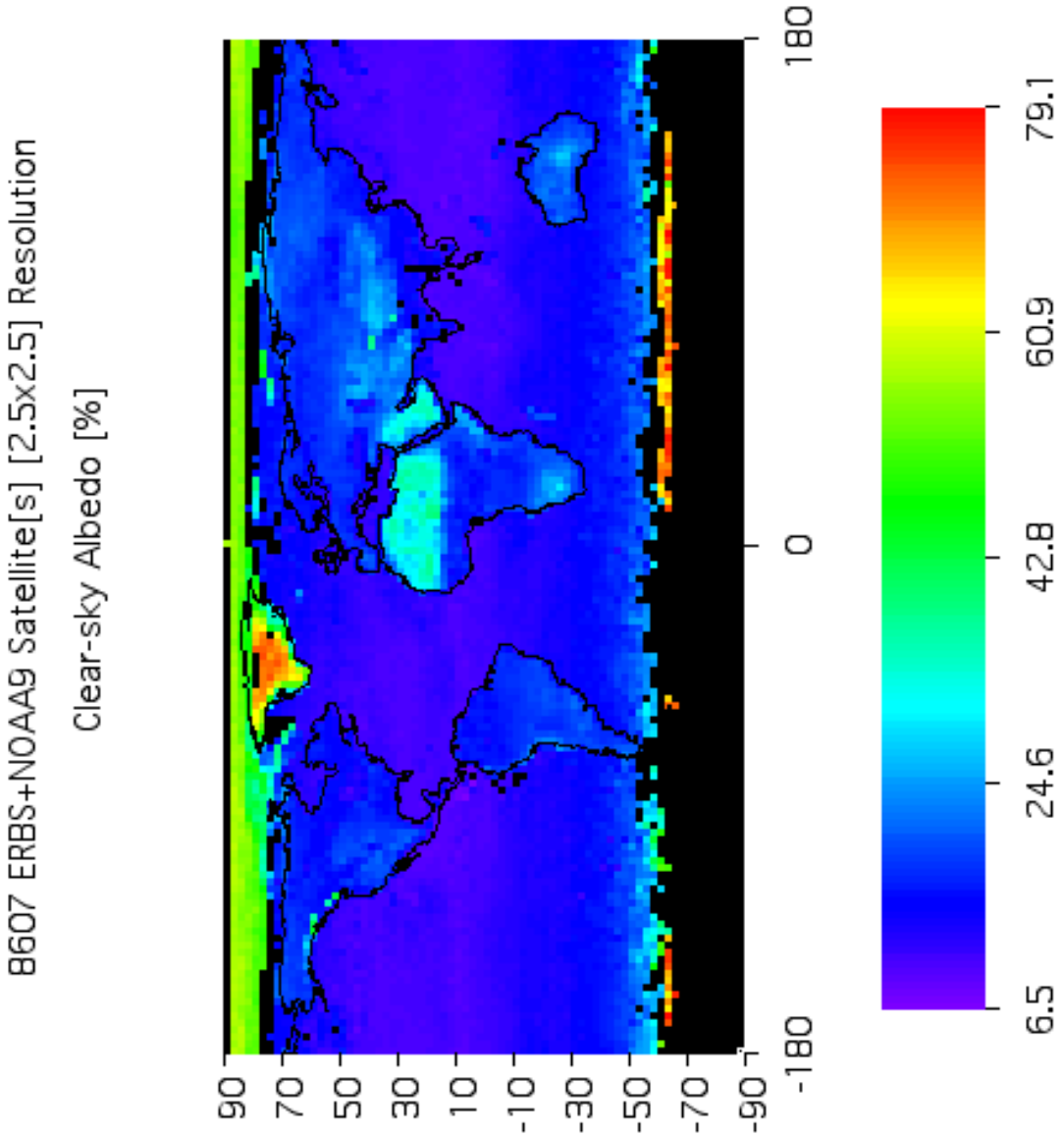



**Figure 3.10. Map of Earth's Clear-sky Albedo – July 1986. Data source: NASA Earth Radiation Budget Experiment and NOAA-9 Satellites.**

# The Role of Actual Data in Mathematical Models

Answer the following questions on your own in complete sentences. You will need to use additional sheets of paper to answer all the questions completely.

1. How does the value for the average surface temperature of the earth without albedo compare with the value you obtained with your own spreadsheet model? Is this value what you would expect?

2. Compare the value of the surface temperature of the earth without albedo, with the average surface temperature with albedo. Is this what you would expect? Explain your reasoning.

3. Examine and compare the References: Map of Earth's Albedo with Clear-sky for January (*Figure 3.1.9, page 101*) and July (*Figure 3.1.10, page 102*). Answer the questions below.

   a. What similarities do you see between the two maps? Are these expected? Explain.

   b. What are the major differences between the two maps? Explain why you think these differences occur.

   c. In the past, the earth has been immersed in a series of Ice Ages. What changes would you expect to see in an albedo map of the earth during one of these ice ages?

4. What effect, if any, do you think the presence of humanity has upon the albedo of the earth? Explain your answer.

5. The actual average temperature at the earth's surface is 15ºC, that of Venus is 430ºC and that of Mars is – 45ºC. How do the theoretical values determined by GEEBITT compare with the true values? What does this indicate about the GEEBITT model?

6. Do you think it is possible to produce a model that is an exact simulation of the real world? Defend your answer.

# Deforestation and Urban Heat Islands

Write a 300 word scientific essay that addresses temperature changes as a result of variations in albedo on the earth's surface and atmosphere. (Refer to this topic's Real World Problem on page 60). How will removing forests and replacing them with agriculture and/or pastures affect albedo? Do you think large scale deforestation in the Amazon will significantly influence local and global temperatures? Would this cause warming or cooling? What are other important factors besides albedo that control temperature?

On a smaller scale, cities replace vegetation with buildings, producing Urban Heat Islands. Why does the city warm as reflectivity increases? Justify your responses with evidence from your Albedo Calculator and GEEBITT experiments. Include examples found on the Internet of areas where humans may be changing albedo and temperature. Use the Reference: Regional Effects of Human Development – Deforestation. (*Figures 3.2 & 3.3 on page 95*)

Topic

# 4 How do Atmospheres Affect Planetary Temperatures?


**Activity A** How do Atmospheres Interact with Solar Energy?

**Activity B** How do Atmospheres Produce their Effect Upon Surface Temperatures?

**Activity C** Can We Model an Atmosphere's Effect Upon a Planet's Surface Temperature?

**Activity D** Can Venus and Mars Be Made Habitable?

# Considering a Real World Problem

## *Culprits of Climate Warming and Cooling*

When we speak of climate we generally think in terms of long time scales – decades or centuries. A great debate about climate has been ongoing for more then 30 years concerning the culprits of climate change and their importance. We know that many factors help produce a planet's climate. On Earth, we know both human and natural activities play roles in the climate system. A major challenge facing climate researchers is to identify significant relationships between these factors and explain their influence on climate in ways that are objective and useful to the public and to policymakers.

Scientists believe Earth's early climate naturally fluctuated between ice ages and fairly warm periods. While direct measurements of global climate began in the 20th century, scientists have discovered "proxy" measures of climate in ice cores, tree rings, pollen remains, and ocean sediments that enable them to construct a history of Earth's climate.

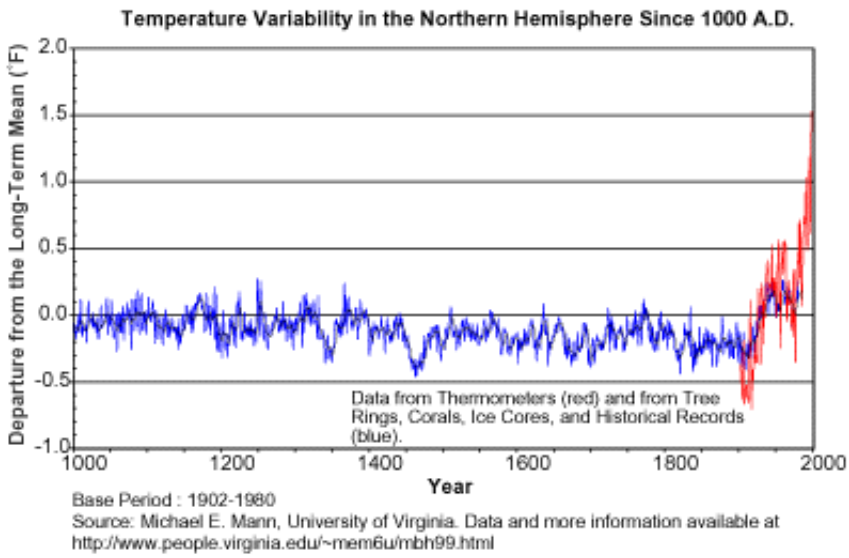



**Figure 4.1. Historical temperature variability in the Northern Hemisphere.**

By most assessments, the climate over the past 1000 years has continued to fluctuate but to a much lesser degree. This fairly stable range of variability has had two notable exceptions. From the 9th to the 14th centuries there was a period known as the Medieval Warming and then the Little Ice Age occurred from the 16th to 19th century. Figure 4.1 above depicts departures from the mean global temperature over the past 1000 years.

In addition to changes in Earth's climate, throughout Earth's history the amount of gases in the atmosphere has also varied significantly. One of these gases is carbon dioxide. Carbon dioxide ($CO_2$) is produced from many different sources. Some examples include: forest fires, human-made combustion of fossil fuels, volcanic eruptions, decayed plants and animals, evaporation from the ocean and human breathing. It is removed from the atmosphere by several processes or *sinks*, such as photosynthesis, ocean plankton and forests and grasslands.

In 1958, Dave Keeling began measuring atmospheric $CO_2$ concentrations from Mauna Loa,

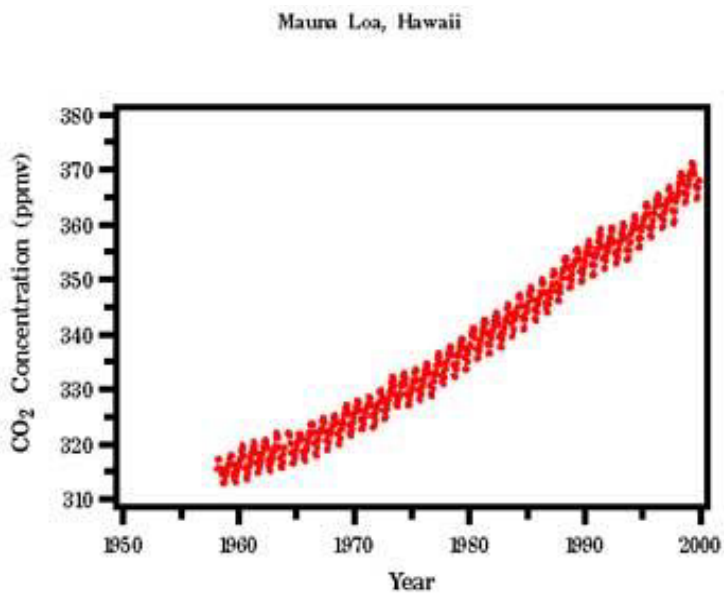



**Figure 4.2. Carbon dioxide concentration. Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography).**

Hawaii. The graph in figure 4.2 shows the data obtained by Keeling and Whorf (1998), representing the longest continuous record of directly measured $CO_2$ concentrations.

Consider that at the end of the 18th century, the beginning of a time referred to as the Industrial Revolution, $CO_2$ concentrations were 280 parts per million and rose to 370 parts per million during the 20th century. They continue to increase at an annual rate of 1.2 parts per million.

Interestingly, at the beginning of the 18th century the world's population reached 1 billion. In the period after World II, there was a "baby boom," with the world's population increasing dramatically. Today, Earth is home to 6.5 billion humans. Current growth is exponential, with the highest rates and populations found in developing countries in Asia, Africa and Latin America. Figure 4.3 illustrates the actual and projected growths in global population.

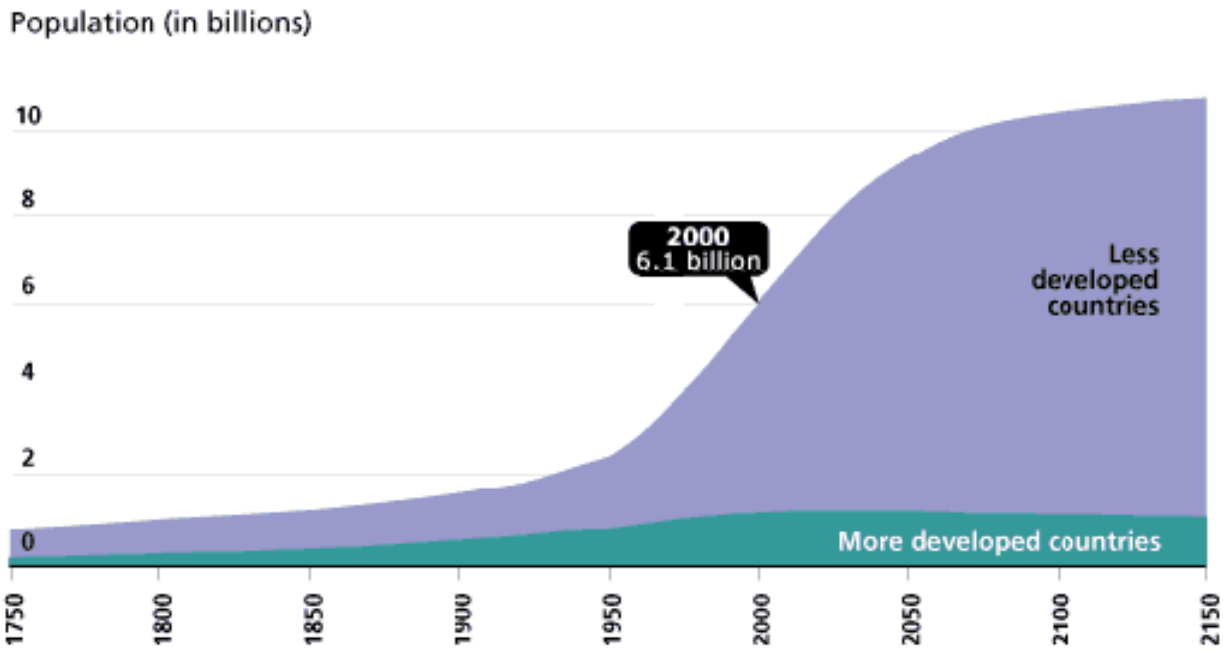



**Figure 4.3. World population record and projection. Source: United Nations, World Population Prospects, 1998 Revision; and estimates by the Population Reference Bureau.**

Using the data presented above, the understandings you gained throughout the *What Determines a Planet's Climate?* module and any other reference materials you obtain, write an essay that addresses the stated real world problem. Be sure to support all your claims with evidence and include responses to the following questions.

**Problem:** What are the significant factors that influence a planet's climate and in particular Earth? What are the important relationships among these factors? Explain your response in an objective, scientific, clear and useful way for the public and policymakers.

How might trends in carbon dioxide, temperature and population over the past century relate to the greenhouse effect and Earth's climate? Be sure to include an explanation of your understanding of how the greenhouse effect works and the influence that these trends may have on this process and Earth's climate.

What if there is a strengthening of the greenhouse effect caused by human activities? How might other factors that affect Earth's climate respond? For example, how could the Earth's albedo change? In turn, would these changes in different albedo factors produce different affects on Earth climate?

What makes carbon dioxide such an important greenhouse gas in terms of changes in its atmospheric concentrations and in the 21st century?

**References for further study:**

Carbon Dioxide Information Analysis Center. Trends: Carbon Dioxide.
*http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm*

NASA Goddard Institute for Space Studies. Global Temperature Trends – 2002 Summation.
*http://www.giss.nasa.gov/research/observe/surftemp/*

Population Reference Bureau. Human Population.
*http://www.prb.org/Content/NavigationMenu/PRB/Educators/Human_Population/Population_Growth/Population_Growth.htm*

U.S. Environmental Protection Agency. Global Warming – Climate.
*http://yosemite.epa.gov/oar/globalwarming.nsf/content/ClimateAtmosphericChangeVariability.html*

# Activity A

## How do Atmospheres Interact with Solar Energy?

### Overview

In class you have been discussing the various roles a planet's atmosphere plays in maintaining its surface temperature. While experimenting with the physical models, you discovered that, in general, an atmosphere has a warming effect upon planetary surface temperature. This warming ability of atmospheres has been given an identifying name: the "greenhouse effect." In this topic you will be investigating various aspects of the greenhouse effect and how an atmosphere produces it.

Reconsider your results from Topic 3, Activity C: The Role of Actual Data in Mathematical Models:

| Planet | "Gray" Body Temperature | | Actual Surface Temperature | | Percent Difference (from K) | Is An Atmosphere Present? |
|---|---|---|---|---|---|---|
| | K | ºC | K | ºC | | |
| Mercury | | | | | | |
| Venus | | | | | | |
| Earth | | | | | | |
| Mars | | | | | | |

**Table 4.1.**

Notice that all the planets with atmospheres have higher actual surface temperatures than what is expected. By comparing the values for Mercury and Venus, you can also see that just the albedo and distance from the source of energy cannot account for these differences. How does the atmosphere of a planet produce this increase in surface temperature, the greenhouse effect? After some discussion with your classmates as to possible answers to this question, do a literature search and discover as much as you can about the atmospheres of these planets. Then, together as a class you try to reduce the number of your proposed hypotheses through further discussion. In the second part of this activity, you will investigate one of the properties of the atmosphere in detail by performing another physical experiment. The results of this experiment will then be compared with the hypotheses that remained at the end of the last discussion.

### Learning Objectives

- ✓ State that an atmosphere has an overall warming effect upon a planet.
- ✓ Describe major characteristics of the atmospheres of Venus, Earth and Mars.
- ✓ State that the magnitude of that effect depends upon specific characteristics of the atmosphere.

- ✓ Observe and measure the temperature changes of gases exposed to light.
- ✓ Identify this warming effect of the atmosphere as the greenhouse effect.
- ✓ Briefly describe how an atmosphere produces the greenhouse effect.

## Relevance

The main question you need to consider in this activity is how do atmospheres produce the greenhouse effect? When you compared the actual surface temperatures, albedos and distances from the sun of Venus and Mercury along with images of both planets, it became obvious that the atmosphere of Venus must play a role in determining the magnitude of the difference of the surface temperatures of these two planets. Earth also has an atmosphere, but is not nearly as warm as Venus. Think about the reasons that may explain this difference. Do you think Venus could ever become more Earth-like? Do you think Earth's atmosphere could ever cause it to become as warm as Venus? This last question alone makes it abundantly clear why we need to understand how an atmosphere produces the greenhouse effect.

# How do Atmospheres Interact with Solar Energy?

## Part 1 – Discussion and Literature Search

### Materials

Images of Mercury, Venus, Earth and Mars
Access to the Internet or a library with planetary science references.

### Methods

**Preliminary Discussion and Preparation**

1. Class discussion of the effects of atmospheres and clouds upon the surface temperatures of planets based upon what has been observed so far.
2. View images of Mercury, Venus, Earth and Mars and relate these observations to your discussion and the differences in predicted and observed surface temperatures.
3. Suggest possible mechanisms by which the atmospheres of these planets could produce the greenhouse effect.

**Perform a Literature Search**

1. In order to evaluate your hypotheses, find out as much information as you can about the atmospheres of these planets. Visit some sites on the Internet, such as NASA's National Space Science Data Center at http://nssdc.gsfc.nasa.gov/ or utilize your library to discover this information.
2. Enter your findings in table 4.2 on the Investigation Sheet: How do Atmospheres Interact with Solar Energy?

**Data Analysis and Consensus**

1. Based on the information you have collected, propose a hypothesis as to how an atmosphere is able to produce the greenhouse effect.
2. Present your hypothesis to the class and compare and contrast it with the other groups' hypotheses.

## Part 2 – Physical Experiment

In order to clarify the potential effects of the various characteristics of atmospheres that you have contrasted and compared, you will now perform an experiment on one of those characteristics, the composition of the atmosphere. You will take samples of air (a mixture) and carbon dioxide (a compound), expose them to light and observe the resulting temperature

changes over time. You will use the results of this experiment to re-evaluate the hypotheses that the class has made in Part 1 of this Activity. (*Please note that this experiment was adapted from Activity C9 of Part II of The Global Warming Project, http://www.letus.northwestern.edu:16080/projects/gw/. This site is an excellent source of materials related to Global Warming.*)

## Materials

Three 250 ml volumetric flasks
Three stoppers with holes (to seal the flasks)
One stopper without a hole
Large trough/pan of water
A small, thin square of glass
One short glass tube to be inserted into one of the stoppers
0.5 meter of flexible tubing to run from the glass tube
2 digital thermometers to be inserted into the other two stoppers
2 100-Watt heat lamps
Three Alka-Seltzer tablets

## Methods

**Preliminary Planning**

1. You will need to prepare two samples, one of air and one of pure carbon dioxide in order to make the required comparison.
2. To collect a sample of air, simply take a dry 250 ml volumetric flasks and place a stopper with one of the thermometers inserted into it, sealing the flask tightly.
3. A more complicated procedure has to be performed to produce a sample of pure carbon dioxide. Follow the steps listed below carefully:
    a. Fill the trough or pan with water.
    b. Completely fill one of the unused volumetric flasks with water, and cover it with the thin glass plate, being sure not to leave any air bubbles in the flask. This flask should now contain only water.
    c. Invert the flask containing water while holding the glass plate tightly to the opening of the flask.
    d. Place the inverted flask with the glass plate into the trough of water so that it stands upside down.
    e. Remove the glass plate with the neck of the flask under water. The flask should remain full of water and no air bubbles should be seen. If any air is present, repeat steps b through e. Have someone hold the flask so that it does not tip over.
    f. Prepare a third flask by filling it with approximately 150 ml of water. Prepare a stopper by inserting a glass tube through it. Run the 0.5-meter of flexible tubing from the glass tube and into the trough so that the end remains immersed under water. Do not put the tubing into the inverted flask, yet.
    g. Drop two Alka-Seltzer tablets into the water of the third flask and quickly seal it with the stopper connected to the glass tube and flexible tubing. You should immediately

see bubbles escape through the end of the tubing under water. Do not collect these initial bubbles as they contain some of the air from the third flask.

h. After two minutes, move the immersed end of the tube so that it is under the immersed open mouth of the inverted flask. Carbon dioxide gas should begin to collect in this flask, and the water level should descend. Continue collecting until the flask is full of carbon dioxide gas.

i. Once the flask is full of gas, seal the flask with the solid stopper, being careful to keep the mouth of the flask under water at all times.

j. Remove the sealed flask from the trough, and place it right side up on a table. Quickly replace the solid stopper with a second holed stopper also with a thermometer inserted through it. If you do this quickly enough the carbon dioxide will remain in the flask due to its density being greater than that of air.

k. At this point you should have two volumetric flasks sealed with stoppers containing digital thermometers to use for the rest of the investigation.

4. Prepare an experimental plan by completing and submitting the Experimental Design Proposal and Methodology for a Controlled Experiment handouts.

**Experimentation and Observation**

1. Set up the experiment based upon your Experimental Design Proposal.
2. Each team will follow a common protocol by taking measurements of the temperatures of the two samples of gas every minute for at least 20 minutes.
3. Record your data in the Data Sheet: Comparing Air and Carbon Dioxide.

**Data Analysis, Comparisons and Consensus**

1. Review the data collected by your team.
2. Analyze your data by completing the Data Sheet: Experimental Results.
3. Coordinate your team presentation to the class.
4. Contribute to the class discussion of everyone's results. Based on this discussion, complete the Data Sheet: Investigative Team Consensus.
5. Answer all the investigation Questions at the conclusion of your experiment and analysis of the data you collected.

**Investigation Notebook**

1. Data Sheet: How do Atmospheres Interact with Solar Energy?
2. Data Sheet: Experimental Design Proposal
3. Data Sheet: Methodology for a Controlled Experiment
4. Data Sheet: Comparing Air and Carbon Dioxide
5. Data Sheet: Experimental Results
6. Data Sheet: Investigative Team Consensus
7. Questions: How do Atmospheres Interact with Solar Energy?

# How do Atmospheres Interact with Solar Energy?

Fill in table 4.2 below as you collect information about the atmospheres of Mercury, Venus, Earth and Mars. As you complete the table you should be considering what these atmospheres have in common and how they differ. Are any of the hypotheses the class put forward during the discussion supported or weakened by this information?

| **Planet** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Mercury | | | | | | | |
| Venus | | | | | | | |
| Earth | | | | | | | |
| Mars | | | | | | | |

**Table 4.2. What characteristic of an atmosphere is responsible for the greenhouse effect?**

1. Do you notice any similarities between the characteristics of these atmospheres? Are there differences in observed and theoretical surface temperatures?

2. Which characteristic of a planet's atmosphere do you think is the primary agent of the warming effect of the atmosphere? Justify your answer.

# Experimental Design Proposal

Before planning how to carry out your experiment, propose a hypothesis for your experiment and determine the limitations of the experiment. Be sure to discuss these with your instructor after your team has come to a consensus.

## Hypothesis

You have two samples of gas: one containing air and the other carbon dioxide. How do you expect these samples to respond when heated by light, and then allowed to cool off?

## Experimental Limitations

How do the materials used in this experiment differ from the objects they are simulating?

How do other experimental conditions compare to the conditions that are being simulated?

## Experimental Expectations

What order of magnitude do you expect in the difference in the results of your two samples?

# Methodology for a Controlled Experiment

Design an experiment to determine if the composition of a planet's atmosphere can affect its surface temperature. You have two samples of "atmospheres" – one containing air and the other pure carbon dioxide. Your group should be divided into two sub-teams. One team should experiment with the sample of air, the other should experiment with the sample of carbon dioxide. Be sure both sub-teams establish a common set of experimental procedures before carrying out the investigation.

| Laboratory Materials | Simulated Object |
|---|---|
| Light source | |
| Sample of air | |
| Sample of carbon dioxide | |

## Experimental Procedure

Indicate the steps you will take in order to obtain your data.

## Analysis of Experimental Variables

List all the characteristics that you could change during your experiment.

Which variable is your independent variable?

Which variable is your dependent variable?

# Comparing Air and Carbon Dioxide

Record the temperature of your sample every minute for at least 20 minutes in table 4.3 below. When both sub-teams are finished, exchange data and fill in the rest of your table.

| Time (minute) | Temperature in ºC | |
|---|---|---|
| | Air Sample | Carbon Dioxide Sample |
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |
| 11 | | |
| 12 | | |
| 13 | | |
| 14 | | |
| 15 | | |
| 16 | | |
| 17 | | |
| 18 | | |
| 19 | | |
| 20 | | |

**Table 4.3. Observed Warming of Air and Carbon Dioxide Samples.**

**Examine your data and discuss the following questions with your team:**

1. Do you notice major differences between the observed data for the two samples?
2. Are there similarities?
3. Do the differences and similarities support or not support your hypothesis?

## Experimental Results

Graph your data and extrapolate your final temperatures.

Plot the data from both samples on one graph. Be sure to keep track of which data goes with which sample. Extrapolate an equilibrium temperature for each sample, if possible.

Based on your graph, what conclusions can you make as to the effect of the composition of atmosphere upon its temperature?

# Investigative Team Consensus

After all the teams have completed their experiments and analyzed their data, reconvene to discuss your findings. Each team's findings should be placed on the board in a table similar to the one below, table 4.4. Fill in your copy of the table with the results of the various teams as they are written on the board.

## Summary of all Teams' Results

| Team | Experimental Parameters | Air Temperature | Carbon Dioxide Temperature | ΔT | ΔT/Time |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Table 4.4. All Teams' Results.**

# How do Atmospheres Interact with Solar Energy?

Answer the following questions on your own in complete sentences. Use additional sheets of paper if necessary.

1. How would Earth be different if the greenhouse effect did not exist in its atmosphere?

2. How would Venus be different if its atmosphere did not supply the same effect?

3. Based on your answers above, is the greenhouse effect an advantage or a disadvantage to a planet's surface?

4. How could we determine if there are other features of an atmosphere that contribute to the greenhouse effect produced by that atmosphere?

5. Is it really necessary for us to know the exact cause of the greenhouse effect? Why or why not?

# Activity B

## How do Atmospheres Produce their Effect Upon Surface Temperatures?

### Overview

After investigating the warming effect of a planet's atmosphere in Activity A, you attempted to relate the greenhouse factor of the model to actual characteristics of the planetary atmospheres. At the end you were left with more questions than answers. Were you able to make any concrete conclusions? Do you know if all of the components of the atmosphere have an equal effect upon the surface temperature? If not, which atmospheric components are most effective in warming a planet? How exactly do they produce this warming effect? Can human activities influence any of these components?

In this activity, you will conduct three simulations to demonstrate how the atmosphere of a planet (Earth, in particular) can affect its surface temperature. Your instructor will describe these simulations. You will then be asked to evaluate the significance of these simulations with regard to explaining the greenhouse effect.

In each simulation, you will need to record the amounts of energy flowing into and out of the various parts of a system. This system will include the sun, the planet's surface and eventually the atmosphere of the planet. By keeping track of the energy inputs and outputs of the system, you will be able to determine its energy budget. By comparing energy budgets of three systems, you will be able to answer some of your remaining questions.

### Learning Objectives

- ✓ Describe the effect of nitrogen and oxygen on incoming and outgoing electromagnetic energy.
- ✓ Describe the effect of carbon dioxide and water vapor on incoming and outgoing electromagnetic energy.
- ✓ Define "greenhouse gas" and state its effect on the surface temperature of a planet.

### Relevance

Even though a model may successfully simulate conditions in the real world, it may not be doing so through the same processes as in the real world. Scientists need to understand how their models obtain their results, and be able to interpret these results with respect to the real world processes that are being represented.

Climate models are used both as tools to deepen our understanding of how the climate system works, as well as to make predictions about future climate. One of the most often misunderstood aspects of the climate system is the greenhouse effect; how it works and the

relative amounts and warming effects of different gases. These understandings are essential to evaluate how changes in concentrations of atmospheric greenhouse gases will influence this process and in turn, produce a positive or negative forcing on our climate.

If the warming effect of greenhouse gases can be understood, then you also should be able to develop a perspective as to whether or not human beings can influence the amounts of these gases in the atmosphere, as well as hypotheses on what effects these gases may have on the earth's climate system. This is an important step toward being able to make well-informed choices about many things that help us sustain healthy and productive lives and contribute to Earth's habitable climate, including the water we drink, the air we breathe, the energy we use and the land we live on.

# How do Atmospheres Produce their Effect Upon Surface Temperatures?

Before beginning the simulations you should review Activity B from Topic 2 (the Local Radiation Balance model). There will be a brief discussion of the results you obtained from your experiments with that model and how those results pertain to the real world.

You will then examine a simple system consisting of the sun and a featureless planet (referred to as a black body) and perform three simulations. In these simulations, one student will play the role of the sun and a second student will play that of the earth's surface.

You will use play money to represent incoming high frequency solar energy (100 dollar bills) and outgoing low frequency infrared energy (any bill with denomination less than 100). At different stages of the activity, other students will be included to represent molecules of oxygen and nitrogen in the atmosphere and finally greenhouse gases. Each student will follow specific rules as he or she interacts with the energy represented by the play money. All students will observe the three simulations, record their observations on handouts, complete an energy budget diagram for each simulation, and then answer specific questions about each simulation.

## Materials

Set of play money: $100, $50, $20, $10, $5 and $1 bills
A copy of the Energy Interaction Protocols for the simulations (*See page 126*)

## Methods

### Preliminary Discussion and Preparation

1. A class discussion and review of Activity B, Topic 2 (the Local Radiation Balance Model)
2. Review with your classmates (a) the concepts of conservation of energy and (b) the relationship between the temperature of an object and the energy it emits.
3. Describe the energy inputs and outputs of a sun/planet system.

### Perform Three Simulations of a Sun/Planet System

1. Determine the roles of the students in your group.
2. Review the rules for the simulations.
3. Perform Simulation 1: Energy Budgets in Sun/Planet Systems. Complete the associated diagram and table.
4. Perform Simulation 2: Energy Budgets in Sun/Planet Systems. Complete the associated diagram and table.

5. Perform Simulation 3: Energy Budgets in Sun/Planet Systems. Complete the associated diagram and table.

**Data Analysis and Consensus**

1. Compare and contrast the three completed energy budget diagrams.
2. Describe the roles of nitrogen and oxygen in terms of energy in the atmosphere.
3. Describe the roles of the greenhouse gases in terms of energy in the atmosphere.
4. Describe the implications of human contributions to greenhouse gases in the atmosphere.
5. Complete the questions following each simulation.

**Investigation Notebook**

1. Reference: Instructions for Simulations of Energy Budgets in Sun/Planet Systems
2. Data Sheet: Simulation 1 - Energy Budgets in Sun/Planet Systems
3. Data Sheet: Simulation 1 - No Atmosphere - Table 4.5
4. Questions: Simulation 1 - Energy Budgets in Sun/Planet Systems
5. Data Sheet: Simulation 2 - Energy Budgets in Sun/Planet Systems
6. Data Sheet: Simulation 2 - Atmosphere with only Nitrogen and Oxygen - Table 4.6
7. Questions: Simulation 2 - Energy Budgets in Sun/Planet Systems
8. Data Sheet: Simulation 3 - Energy Budgets in Sun/Planet Systems
9. Data Sheet: Simulation 3 - Atmosphere with Nitrogen, Oxygen, Water Vapor and Carbon Dioxide - Table 4.7
10. Questions: Simulation 3 - Energy Budgets in Sun/Planet Systems

# Instructions for Simulations of Energy Budgets in Sun/Planet Systems

Your instructor will divide the class into groups of four students per team. Each group will use the instructions to carry out the following three simulations of a sun/planet system:

1. A planet without an atmosphere.
2. A planet with an atmosphere composed of only nitrogen and oxygen.
3. A planet with an atmosphere of nitrogen, oxygen, carbon dioxide and water vapor.

Each group needs to select one student each to represent:

the sun
the surface of the planet
oxygen and nitrogen in the atmosphere
carbon dioxide and water vapor in the atmosphere

## General Instructions for the Simulations

The students representing the sun and the planet's surface will sit across from one another at a table. The student representing the sun is given a stack of $100 bills in play money. Each dollar represents one unit of energy.

The student representing the planet's surface is given stacks of the other denominations.

The students playing the roles of oxygen, nitrogen, carbon dioxide and water vapor will sit at the sides of the table, between the sun and the planet's surface students.

Each simulation will consist of a series of turns. Go through as many turns as you need in order to be able to complete the diagram associated with the simulation. The planet's surface is assumed to be a blackbody with an albedo of 0.

1. Any part of the system (the sun, the atmosphere or the planet's surface) holding energy releases that energy. The play money is passed to the next player in that direction. The energy released is recorded in the box above the arrow indicating the direction of that energy release.

2. Any part of the system receiving energy must either hold onto (absorb) that energy until the next turn, or immediately pass it on (transmit) in the same direction. The decision to hold onto the energy or pass it on is made according to the Energy Interaction Protocols.
    a. Energy that is absorbed is held onto by the player and recorded in the box representing the atmosphere or the planet's surface.

b. Energy that is transmitted is handed to the next player and recorded in the box above the appropriate arrow for that turn.
c. The player receiving the passed on energy repeats step 2.

3. Each player should check to see that the amount of energy/money they possess agrees with the amount recorded on the handout.

4. End of Turn

Go through as many turns as needed so that you are able to summarize the characteristics and complete the energy budget diagram for each simulation.

### *Energy Interaction Protocols for the Simulations*

1. The Sun – For the short period of time over which these simulations occur, the sun is assumed to have an unlimited amount of energy that is released at a constant rate. The student representing the sun releases the same amount of energy each turn through out the simulation.

2. The Planet's Surface – The student representing the planet's surface must convert all the incident solar radiation/energy to an equal amount of infrared radiation/energy. Incoming infrared radiation/energy remains as infrared radiation/energy. All incoming energy is held by this player for one turn and then released outwards as infrared radiation during the next turn. The play money that was converted into lower denominations is returned to the instructor.

3. The Atmosphere –
   a. Oxygen and Nitrogen gases do not interact with either solar or infrared radiation/energy. The students representing these gases merely pass the energy on to the next player in that direction in exactly the same form as it was received. The solar radiation/energy is merely passed on to the next player in that direction.
   b. Carbon Dioxide and Water Vapor do interact with infrared radiation/energy. All incoming infrared radiation/energy is held by this player for one turn and *then equal amounts are released in all directions* as infrared radiation/energy during the next turn.

# Simulation 1 - Energy Budgets in Sun/Planet Systems

## Simulation 1: No Atmosphere

The student representing the sun uses two $100 bills to represent 200 units of energy to be sent towards the planet.

When the student acting as the planet's surface receives these bills, he/she converts them into $20 bills and sends them back out to space during the next turn.

Perform the simulation as many times as necessary in order to be able to assign numerical values to the inputs and outputs in figure 4.4, shown below.

Label the energy inputs and outputs of the planet-sun system represented in this diagram, inserting the numerical values you obtained from the simulation.

Complete table 4.5 with your observations and then answer the questions that follow.

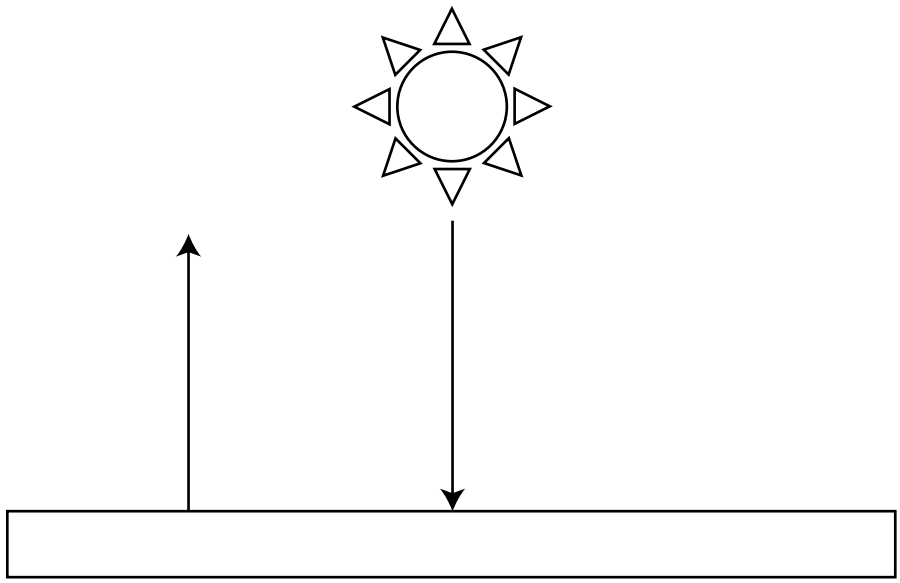


**Figure 4.4. Energy budget simulation of a sun/planet system where the planet has no atmosphere.**

## Simulation 1 - No Atmosphere - Table 4.5

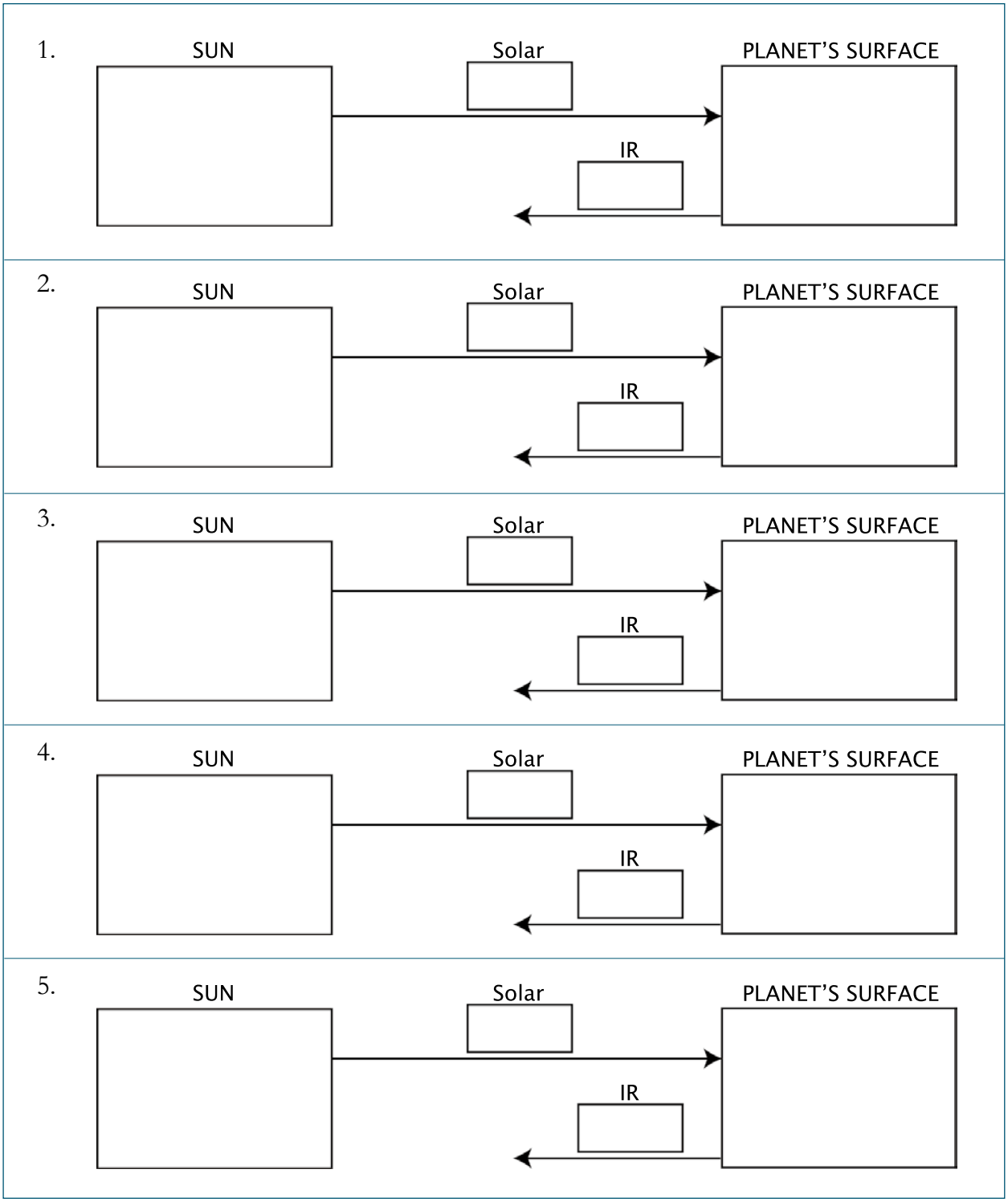



**Table 4.5. Energy budget simulation of a sun/planet system in which the planet has no atmosphere.**

## Simulation 1 - Energy Budgets in Sun/Planet Systems

Answer the following questions after you have completed table 4.5 for simulation 1.

1. What happens to the solar energy after it arrives at the planet's surface?

2. How does this relate to the temperature of the surface?

3. How does the total amount of energy arriving at the surface compare to the total amount leaving the surface?

4. What changes would you expect to see in the simulation if the sun were to emit twice as much energy each turn?

# Simulation 2 - Energy Budgets in Sun/Planet Systems

## Simulation 2: Atmosphere with only Nitrogen and Oxygen

The students representing the sun and the earth do just as they did in the first simulation.

A new student is introduced to the system and sits between them. This student represents the nitrogen and oxygen molecules within the atmosphere. This student observes the transactions between the original two students, following the appropriate Energy Interaction Protocol.

Label all the inputs and outputs of the planet-sun system represented in figure 4.5.

Some of the arrows in this diagram will not be used and may be crossed out. Be prepared to explain why you have crossed out those arrows.

Complete table 4.6 with your observations and then answer the questions that follow.

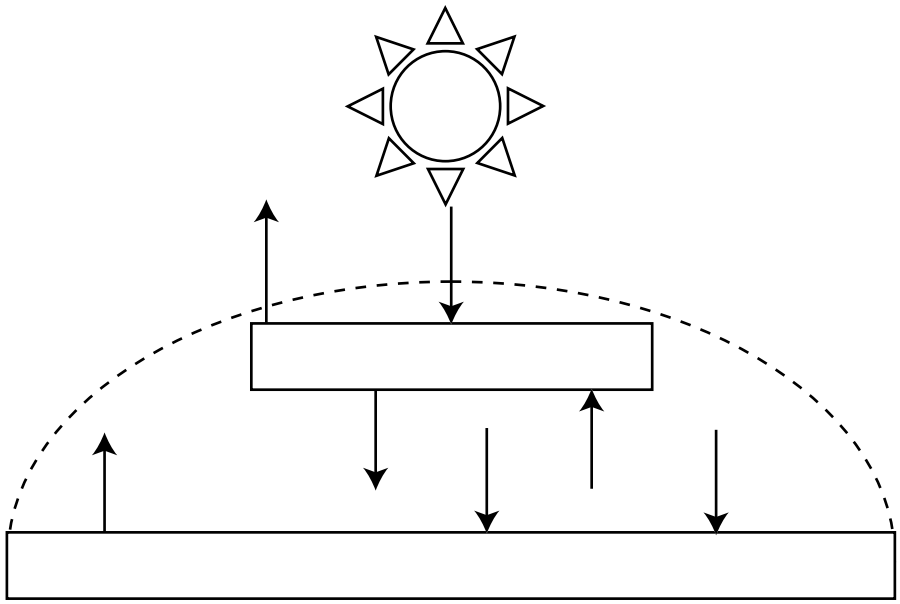


**Figure 4.5. Energy budget simulation of a sun/planet system where the planet has an atmosphere with only nitrogen and oxygen.**

# Simulation 2: Atmosphere with only Nitrogen and Oxygen - Table 4.6

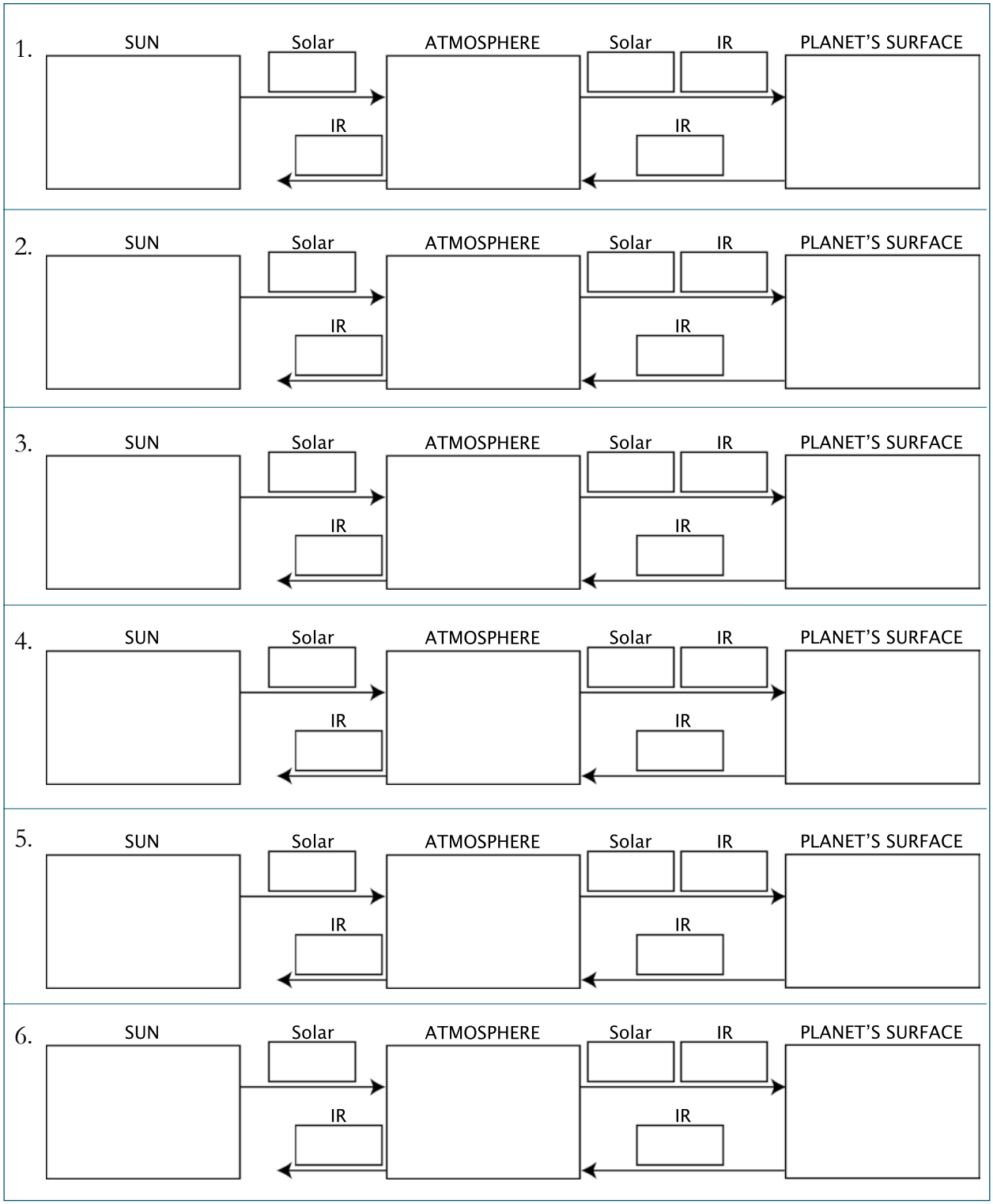



**Table 4.6. Energy budget simulation of a sun/planet system in which the planet has an atmosphere with only nitrogen and oxygen.**

## Simulation 2: Energy Budgets in Sun/Planet Systems

Answer the following questions after you have completed table 4.6 for simulation 2.

1. What effect do oxygen and nitrogen have on the incoming solar energy?

2. What happens to the solar energy that arrives at the planet's surface?

3. What happens to the infrared energy when it passes through the atmosphere?

4. How do these interactions affect the temperature of the surface?

5. How does the total amount of energy arriving at the planet part of the system compare to the total amount leaving that part of the system system?

# Simulation 3: Energy Budgets in Sun/Planet Systems

## Simulation 3: Atmosphere with Nitrogen, Oxygen, Water Vapor and Carbon Dioxide

Again, the students acting as the sun and the earth do just as they did in the first and second simulations.

The student portraying nitrogen and oxygen molecules continues to behave as he or she did in the second simulation.

Another student is introduced to play the role of water and carbon dioxide molecules in the atmosphere, sitting between the earth and sun students and across from the nitrogen/oxygen student. This student follows appropriate instructions from the Energy Interaction Protocols.

Label figure 4.6 completely showing the energy inputs and outputs from the simulation.

Complete table 4.7 with your observations and then answer the questions that follow.

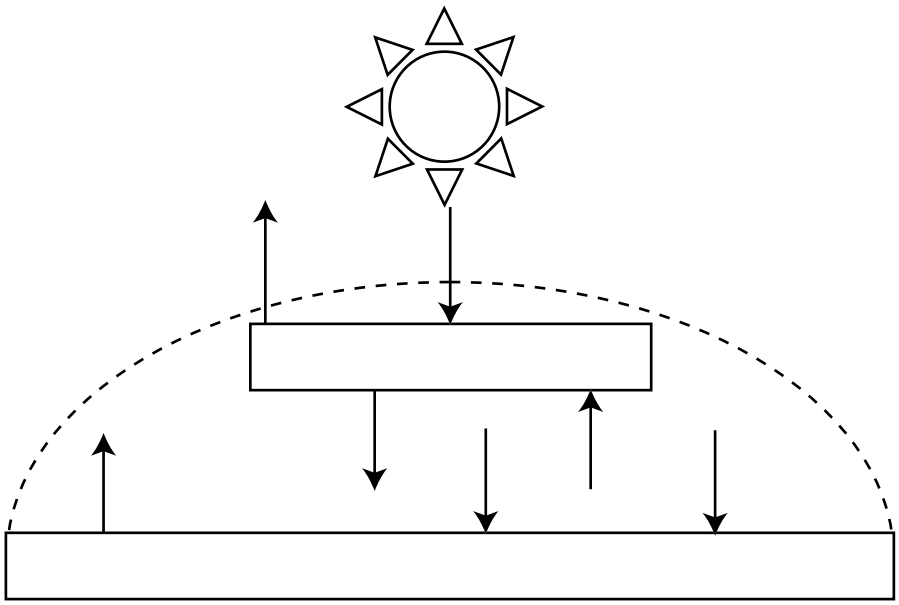


**Figure 4.6. Energy budget simulation of a sun/planet system where the planet has an atmosphere with nitrogen, oxygen, water vapor and carbon dioxide.**

# Simulation 3: Atmosphere with Nitrogen, Oxygen, Water Vapor and Carbon Dioxide - Table 4.7

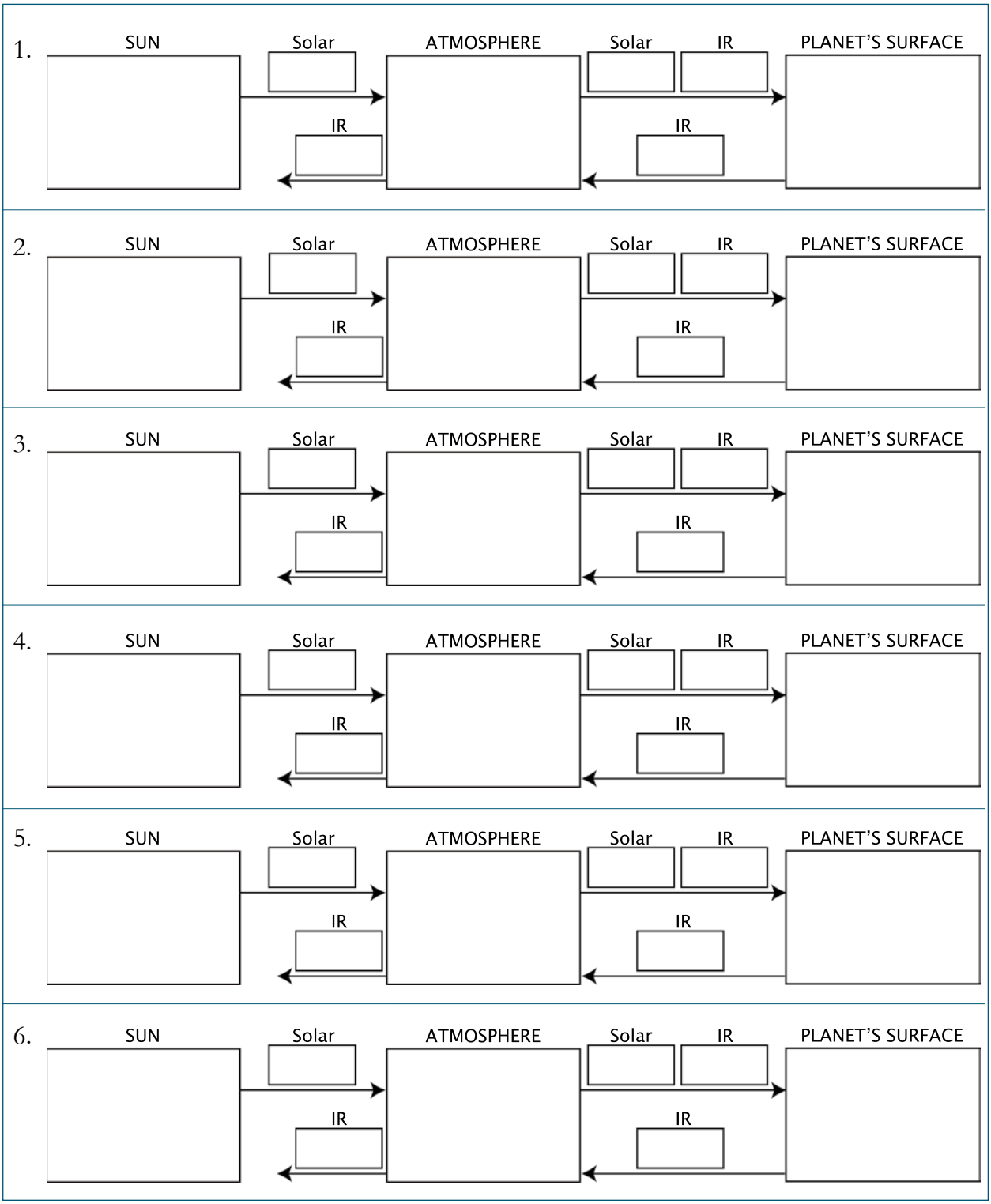



**Table 4.7. Energy budget simulation of a sun/planet system in which the planet has an atmosphere consisting of nitrogen, oxygen, water vapor and carbon dioxide.**

## Simulation 3: Energy Budgets in Sun/Planet Systems

Answer the following questions after you have completed table 4.7 for simulation 3. Use additional sheets of paper if necessary.

1. What effect do carbon dioxide and water vapor have on the incoming solar energy?

2. What happens to the solar energy that arrives at the planet's surface?

3. What happens to the infrared energy when it passes through this atmosphere?

4. What does this do to the temperature of the surface compared to the effects seen in the previous two simulations?

5. How does the total amount of energy arriving at the planet system compare to the total amount leaving the system?

6. How would you expect the temperature of the planet's surface in this simulation to compare with the temperatures of the surface in the other two simulations?

7. Based on your observations of these simulations, what possible modifications can you suggest for your computer model?

# Activity C

## Can We Model an Atmosphere's Effect Upon a Planet's Surface Temperature?

### Overview

In this activity, we consider the question of whether or not the phenomenon of the warming effect of a planet's atmosphere can be modeled effectively in the *Global Equilibrium Energy Balance Interactive Tinker Toy*, GEEBITT. You will use another version of GEEBITT called Mini-GEEBITT, Version B. This version contains another variable that may be adjusted by the user. This variable is called the "greenhouse factor" and its purpose is to mimic the effect of a planet's atmosphere upon the surface temperature of the planet. You will use the actual conditions of the atmospheres of these three planets that you described in Activity A in conjunction with the results of the physical experiment you performed in that activity to predict the relative magnitudes of the greenhouse factors for Earth, Mercury, Venus and Mars. You will then attempt to adjust this factor for GEEBITT models of Earth, Mercury, Venus and Mars to see if it is possible to produce surface temperatures with the models that more accurately portray the true surface temperatures of these planets. You will then compare the values used for this greenhouse factor with your preliminary predictions and try to explain any discrepancies.

### Learning Objectives

- ✓ Use the characteristics of a planet's atmosphere to estimate the magnitude of the greenhouse factor of that planet.
- ✓ Use a mathematical model to determine the greenhouse factor for a planet.
- ✓ Relate the greenhouse factors from the models to the actual conditions of the atmospheres of the planets.
- ✓ Summarize the characteristics of the greenhouse effect.

### Relevance

Mercury is the planet closest to the sun. The average surface temperature on Mercury is 167ºC, while that of second closest planet, Venus, is 430ºC. Obviously, distance alone cannot account for this difference. When examining images of these two planets, the most evident difference between them is Mercury's lack of an atmosphere and the thick atmosphere and clouds that enshroud Venus. What characteristics of the atmosphere provide the greatest contributions to the greenhouse effect? If our mathematical models are to provide truly accurate simulations of the planets, this effect of the atmosphere must also be included correctly in the model.

# Can We Model an Atmosphere's Effect Upon a Planet's Surface Temperature?

Based upon the discrepancies observed between the results of the surface temperatures of the planets produced by the early versions of our mathematical models and the actual temperatures of the planets, GEEBITT has been modified yet again. A factor has been introduced to mimic the observed effect of a planet's atmosphere. This factor is called the Greenhouse factor.

You will use your results from the literature search and the experiment in Activity A to estimate the magnitudes of the greenhouse factors for Mercury, Venus, Earth and Mars. You will then use the modified version of GEEBITT to determine values for this factor for each of these planets that enable the model to produce surface temperatures that are closer to their actual observed surface temperatures. You will then compare these values for the greenhouse factor with your initial predictions and evaluate your hypotheses as to which characteristics of the atmosphere contribute the most to the greenhouse effect.

## Materials

Results from Activity A
Computers loaded with Microsoft Excel software. A maximum of 2-3 students per computer is suggested.
A copy of the spreadsheet mini-GEEBITT, Version B. (This spreadsheet can be downloaded from: http://icp.giss.nasa.gov/education/)

## Methods

### Preliminary discussion and preparation

1. Class review of the role of the greenhouse gases in the atmospheres of planets.
2. How would Earth be different with more or with less greenhouse gases?
3. Review the properties of the GEEBITT computer model.

### Determine the Greenhouse Factor for Earth

1. Locate the greenhouse factor modification in mini-GEEBITT, Version B and determine how to apply it.
2. Use the GEEBITT model to determine a greenhouse factor for Earth so that GEEBITT produces a surface temperature the same as the observed value for Earth. Record this value in table 4.8 in the Data Sheet: Predicting Greenhouse Factors: How Does a Planet's Atmosphere Affect its Temperature?

## Predict the Magnitudes of the Greenhouse Effects for Venus, Mars and Mercury

1. Review your literature search on the characteristics of the atmospheres of Mercury, Venus, Earth and Mars and the results of your physical experiment in Activity A.
2. Predict the relative magnitudes of the greenhouse factors for the other planets.
3. Complete table 4.8 in the Data Sheet: Predicting Greenhouse Factors.

## Experiment With the Modified Version of GEEBITT

1. Use GEEBITT to determine the greenhouse factors for Mercury, Venus, and Mars that enable GEEBITT to produce surface temperatures for these planets that are in agreement with the observed temperatures.
2. Complete the rest of the Data Sheet: Predicting Greenhouse Factors.

## Data Analysis and Consensus

1. Compare these characteristics with the greenhouse factors you determined using GEEBITT with your predictions.
2. Evaluate your hypothesis as to which characteristic(s) of an atmosphere is (are) the main contributors to the greenhouse factor.
3. Present your evaluation to the class and compare and contrast it with other groups' results.

## Investigation Notebook

1. Data Sheet: Predicting Greenhouse Factors.

# Predicting Greenhouse Factors

You have seen that the actual surface temperatures of Mercury, Venus, Earth and Mars differ from the "gray body" temperatures predicted by our mathematical models due to the greenhouse effect of their atmospheres. In Activity A, you performed a literature search and collected information about the characteristics of the atmospheres of these planets. You will now attempt to describe this effect quantitatively.

Your instructor will inform you when to open the spreadsheet, mini-GEEBITT, Version B. This version has been modified to include a Greenhouse Factor to help model the effect of a planet's atmosphere on the average surface temperature of the planet. Your initial task is to input the known conditions for Earth: the luminosity of the sun, average distance between Earth and the sun, and average albedo of Earth. This should produce the same average surface temperature that you achieved with GEEBITT 1. If not, recheck the values you entered into the spreadsheet.

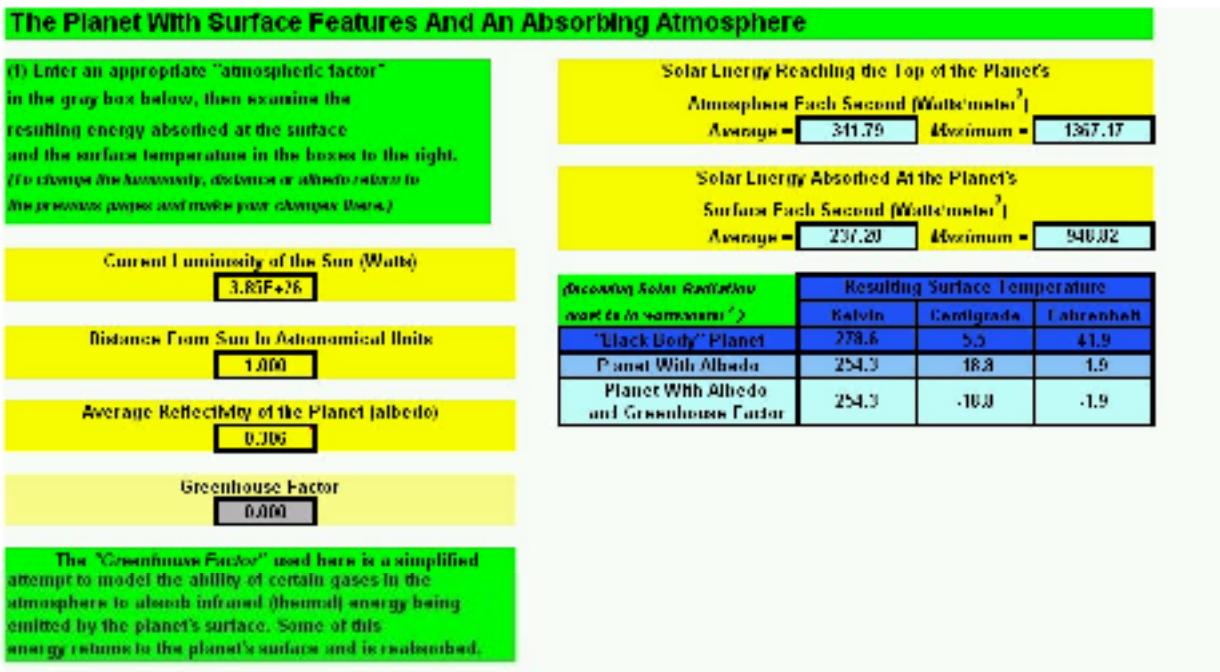



**Figure 4.7. Screenshot of page 3 of the mini-GEEBITT, Version B spreadsheet model. The greenhouse factor appears in the first column with its default value 0.000 displayed in a gray-colored cell.**

In the first column on page 3 of the spreadsheet you will see a gray colored cell for the "Greenhouse Factor." The default value for this factor is 0.000 and we can see that with this value there is no difference in the surface temperature of the planet. You are to determine if there is a numerical value that can be inserted into this greenhouse factor cell that will enable GEEBITT to produce an average surface temperature similar to the actual average surface temperature of Earth. Try several values until you get as close to the actual average surface temperature of Earth as you can. Write your final value in the first cell in table 4.8.

Review the information you obtained in Activity A. Compare all these factors with the differences between the actual surface temperatures and theoretical surface temperatures of these planets. Based on your comparisons, estimate the relative magnitudes of the greenhouse factors for these four planets. Enter your predictions in table 4.8 below.

| **Planet** | **Difference In True & Predicted Surface Temperatures** | **Observed Greenhouse Factor** |
|---|---|---|
| Earth | | |
| | | **Predicted Greenhouse Factor** |
| Mercury | | |
| Venus | | |
| Mars | | |

**Table 4.8. Predicted Greenhouse Factors.**

Give a brief explanation as to why you made these choices.

1. Were you able to find a greenhouse factor for the Earth model that produces the true average surface temperature of the earth? If yes, explain how you found it. If no, explain why you think this was not possible.

2. In your opinion, does this greenhouse factor accurately represent the effect of an atmosphere on Earth's average surface temperature? Explain.

3. Can GEEBITT produce average surface temperatures that are similar to the actual average surface temperatures of the planets being modeled?

Repeat the exercise from above by entering the appropriate values for distances and albedos of Mercury, Mars and Venus into mini-GEEBITT, Version B. Then determine the numerical values for the greenhouse factors of these planets, if there are such values, that can produce average surface temperatures that are close to the true values for each of the planets. Enter these results in table 4.9.

| **Planet** | **Actual Average Surface Temperature** | **"Best" Greenhouse Factor** | **Resulting Average Surface Temperature** |
|---|---|---|---|
| Earth | | | |
| Mercury | | | |
| Venus | | | |
| Mars | | | |

**Table 4.9. "Best" greenhouse factors for modeling planets with GEEBITT.**

4. Based on your results in table 4.9, is there any change in your opinion as to the ability of the greenhouse factor to accurately represent the effect of an atmosphere on a planet's average surface temperature? Explain.

Complete table 4.10 with the appropriate values.

| Planet | "Best" Greenhouse Factor | Predicted Greenhouse Factor | Difference In Magnitudes of Factors |
|---|---|---|---|
| Earth | | | |
| Mercury | | | |
| Venus | | | |
| Mars | | | |

**Table 4.10. Predicted and "best" greenhouse factors.**

5. How do your predictions compare with the values obtained using GEEBITT?

6. What does this say about the basis of your predictions? Would you make any changes?

# Activity D

## Can Venus and Mars Be Made Habitable?

### Overview

The three simulations in the previous activity provided deeper insight into the role greenhouse gases play in maintaining a planet's surface temperature. You should now understand how these gases interact with energy in a planet's atmosphere to provide a warming effect. The greenhouse gases, luminosity of the source, the distance of the planet from the source and the albedo of the planet combine to establish the average temperature of a planet's surface. Can changes in one factor compensate for changes in another factor? Can the effect of increasing amounts of greenhouse gases be alleviated by changes in other factors?

To answer these questions you will again make use of the GEEBITT spreadsheet model that allows you to manipulate the primary factors that determine the average surface temperature of a planet. This spreadsheet model is extremely simplified in that it deals only with a planet's average characteristics. A more complicated model would be necessary for advanced studies. The spreadsheet model will allow you to investigate the overall effects of these factors. Your final task is to determine if there are values for these factors that will allow Mars and/or Venus to maintain an average surface temperature that would be comfortable for human beings. You will then be asked to make some conclusions about these methods and suggest improvements that can be made in this spreadsheet model.

### Learning Objectives

- ✓ Demonstrate the ability to manipulate GEEBITT.
- ✓ Use GEEBITT to determine if there is a combination of the four major factors that can produce habitable average surface temperatures for Venus and Mars.
- ✓ Debate the possibility of terraforming Mars and Venus.
- ✓ Relate the knowledge you have obtained from this module to the quality of humanity's future on Earth.

### Relevance

You have spent a majority of this module developing and using a mathematical model that can determine the average surface temperature of a planet. Even though this model lacks the bells and whistles of the much more complicated General Circulation Models used by climate modelers, it can still be used to answer some basic questions about the potential habitability of planets. By using this model to answer such questions, you can demonstrate the fundamental benefits of models in general, and make some significant conclusions about the choices available for the future.

# Can Venus and Mars Be Made Habitable?

## Materials

Computers loaded with Microsoft Excel software, preferably one per student.
A copy of the spreadsheet climate model GEEBITT, Level 1 (This spreadsheet can be downloaded from: http://icp.giss.nasa.gov/education/)

## Methods

### Preliminary Discussion and Preparation

1. Class discussion of the results from the previous activity. Summarize the role of greenhouse gases in the atmosphere.
2. Discussion of the interaction of the four primary factors for establishing the average surface temperature of a planet.

### Performing the Task

1. Use GEEBITT, Level 1 to determine if there is a realistic combination of factors that can produce habitable surface temperatures for Venus and/or Mars.
2. Record your results in the Data Sheet: Can Venus and/or Mars Be Terraformed?

### Interpreting the Results and Consensus

1. Produce a realistic scenario to explain your combination of factors.
2. Class debate and discussion of results, concluding with a consensus as to the practicality of terraforming Venus and Mars.
3. Discuss the significance of these findings with respect to humanity's future choices.

### Investigation Notebook

1. Data Sheet: Can Venus and/or Mars Be Terraformed?

## Can Venus and/or Mars Be Terraformed?

Open the spreadsheet GEEBITT, Level 1. The first page of this new spreadsheet allows you to manipulate (1) luminosity of the source and (2) distance from the source. On the second page you can adjust (3) reflectivity (albedo) of the planet, and on the third page you can change (4) the amount of greenhouse gases in the planet's atmosphere. When you change any of these factors, the spreadsheet automatically determines the resulting theoretical equilibrium temperature of the planet's surface. This value appears in the box on the upper right of the spreadsheet. Use this model to determine if there is a combination of values for the four main factors that affect a planet's surface temperature that could enable Venus and/or Mars to maintain an average surface temperature comfortable for humans. If you are able to find such a combination, list the values in table 4.11 below.

| Factor | Units | Venus values | Mars values |
|---|---|---|---|
| Luminosity of the Sun | | | |
| Distance from the Sun | | | |
| Albedo | | | |
| Greenhouse Factor | | | |

**Table 4.11. Factors for a theoretical habitable equilibrium temperature for Venus and Mars.**

Describe why you selected these values.

What is the physical significance of your values? What would be different about the planet if these factors could be changed to the values you have suggested?

Do you think this suggestion is practical? Could this suggestion actually be implemented some day?

# Culprits of Climate Warming and Cooling

Write a 1000 word scientific essay that addresses: What are significant factors that influence a planet's climate and in particular Earth? Be sure to explain important relationships among these factors. (Refer to this topic's Real World Problem).

How might trends in carbon dioxide, temperature and population over the past Century relate to the greenhouse effect and Earth's climate? Include a detailed explanation of how the greenhouse effect works. What kinds of influences might these trends have on this process and Earth's climate? Justify your responses with evidence from the various model experiments and simulations you conducted on Topics 1 through 4 with Albedo Calculator, GEEBITT and Simulations of Energy Budgets in Sun/Planet Systems.

Consider the possibility that there may be a strengthening of the greenhouse effect due to additional gases that human activities emit into the atmosphere. How might Earth's albedo change? In turn, how might changes in different albedo factors produce differing affects on Earth's climate?

Finally discuss what makes carbon dioxide such an important greenhouse gas in terms of changes in its atmospheric concentration and in the 21st Century You should include 3 to 5 citations from reference materials, 2 of which should be from sources other than those found on the Internet.

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