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.

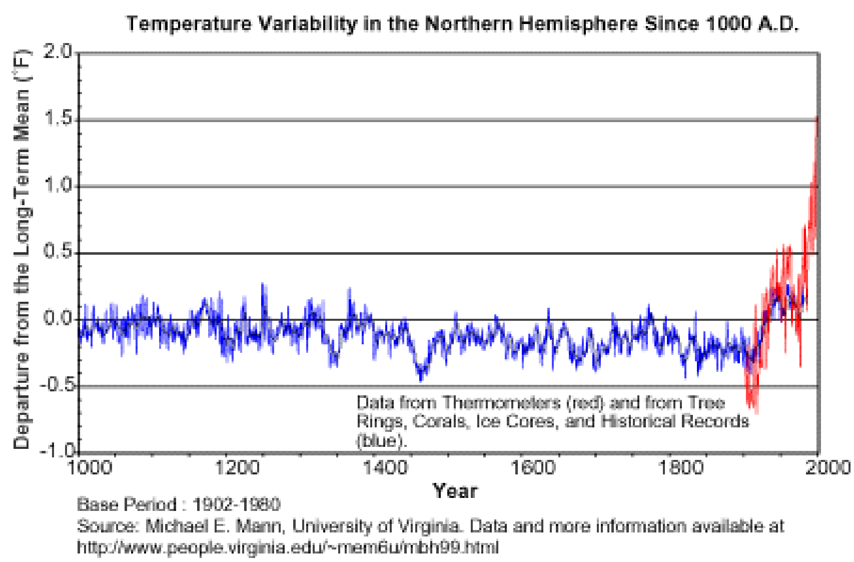


Figure 4.1. Historical temperature variability in the Northern Hemisphere.

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,

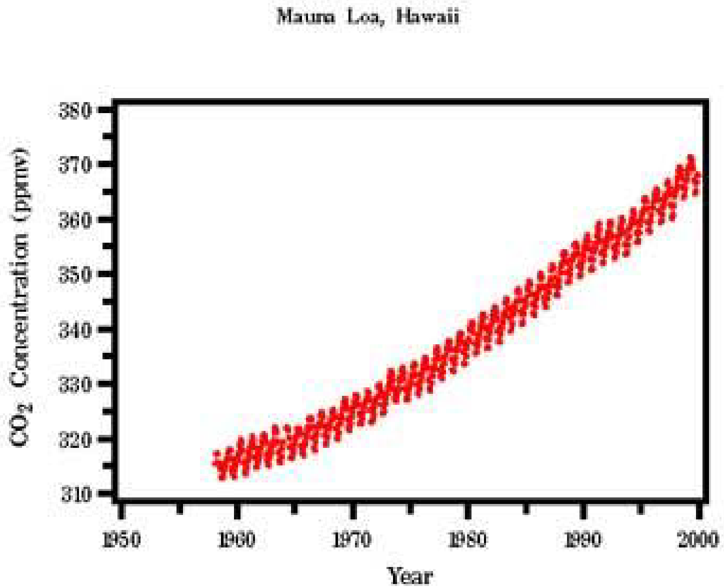


Figure 4.2. Carbon dioxide concentration. Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography).

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.

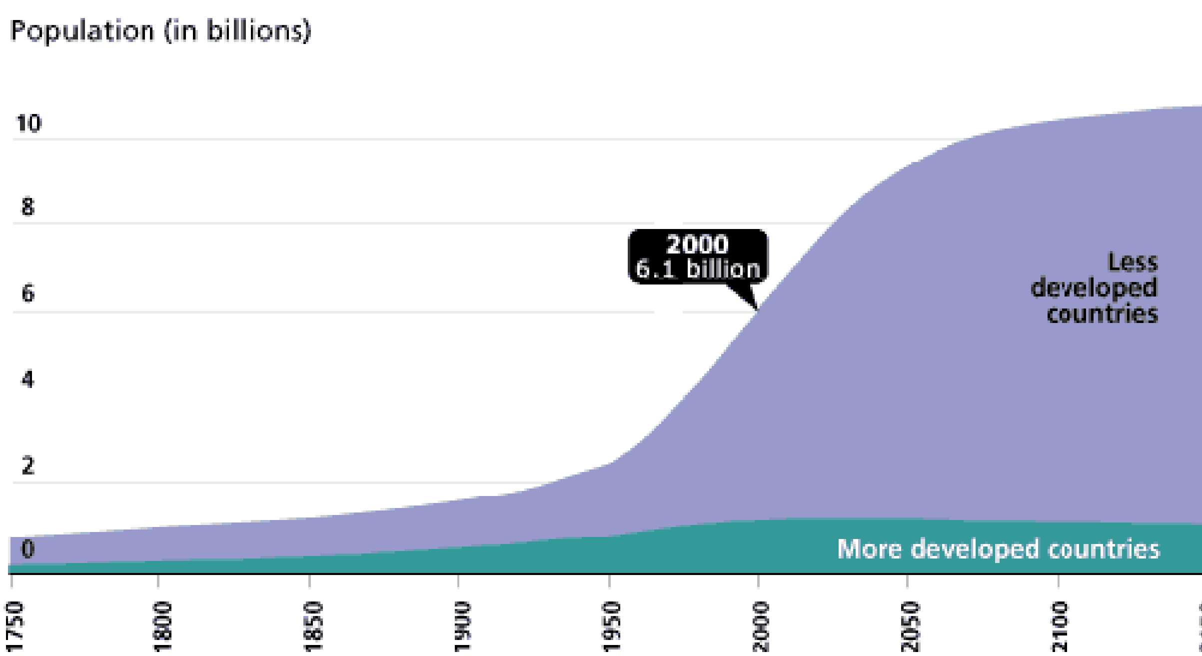


Figure 4.3. World population record and projection. Source: United Nations, World Population Prospects, 1998 Revision; and estimates by the Population Reference Bureau.

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	Is An Atmosphere
	K	ºC	K	ºC	(from K)	Present?
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.

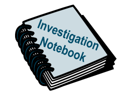
Data Analysis, Comparisons and Consensus

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?

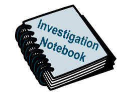
How do other experimental conditions compare to the conditions that are being simulated?

Experimental Expectations

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

Investigation Activity A

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?

Data Sheet Activity A

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.

Questions — Activity A

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.

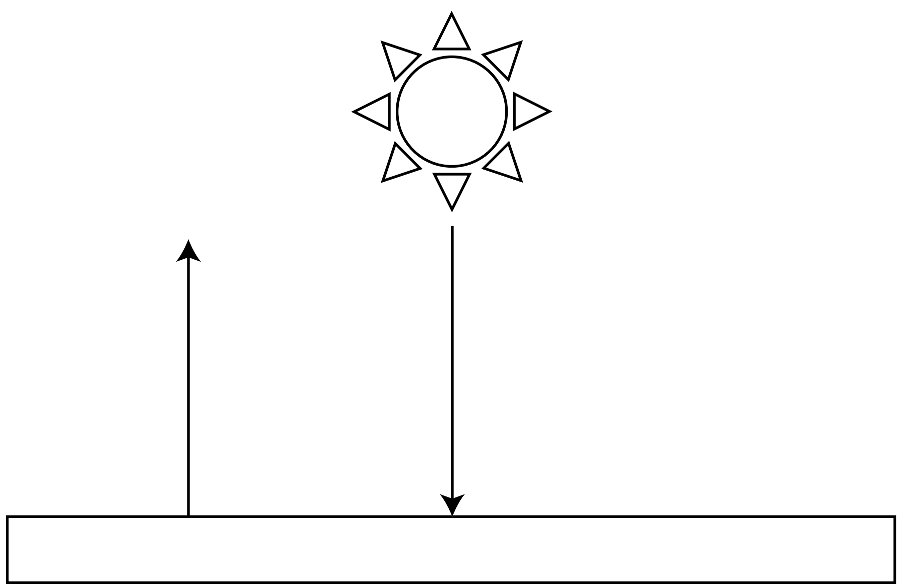


Figure 4.4. Energy budget simulation of a sun/planet system where the planet has no atmosphere.

Simulation 1 - No Atmosphere - Table 4.5

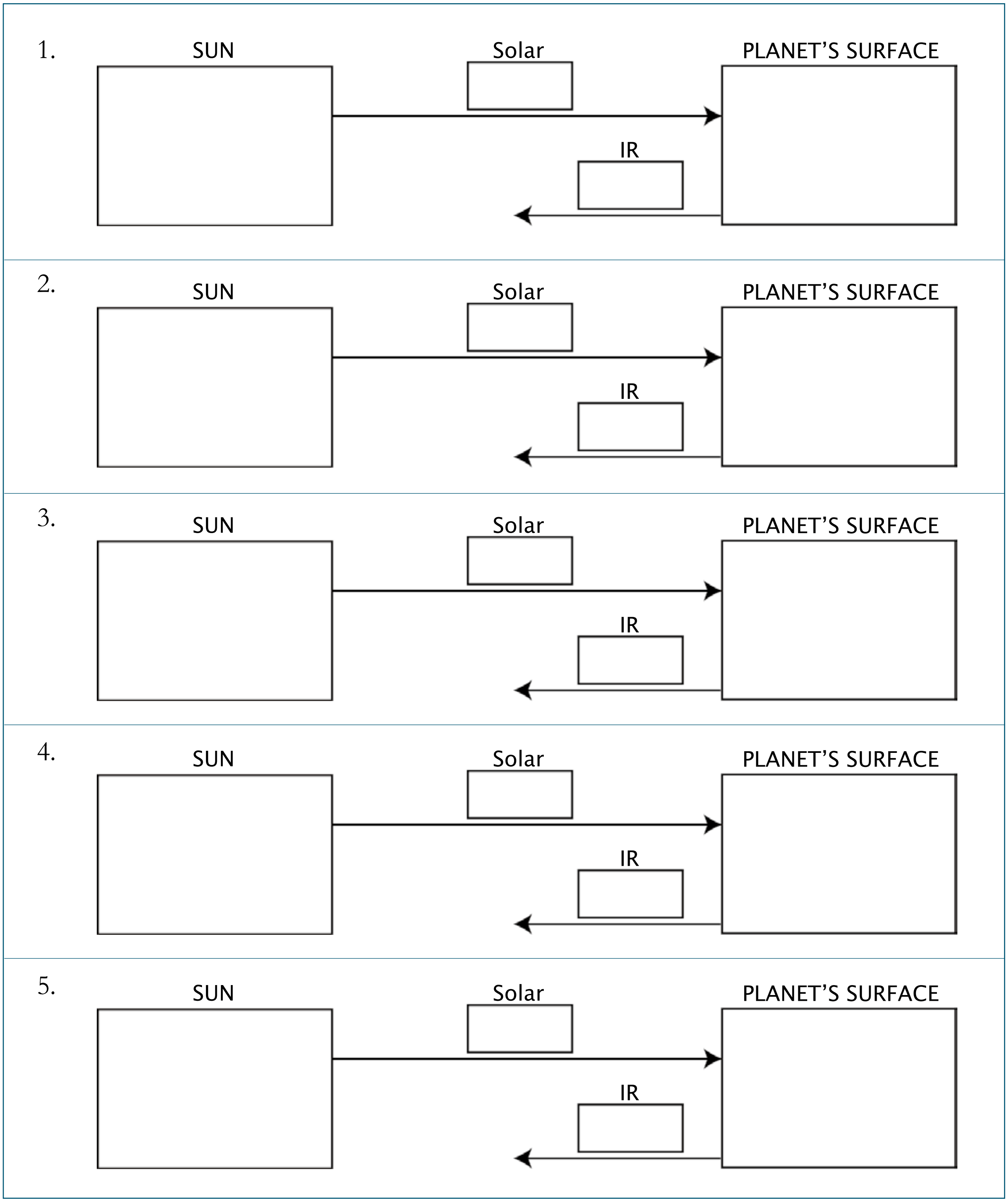


Table 4.5. Energy budget simulation of a sun/planet system in which the planet has no atmosphere.

Questions Activity B

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.

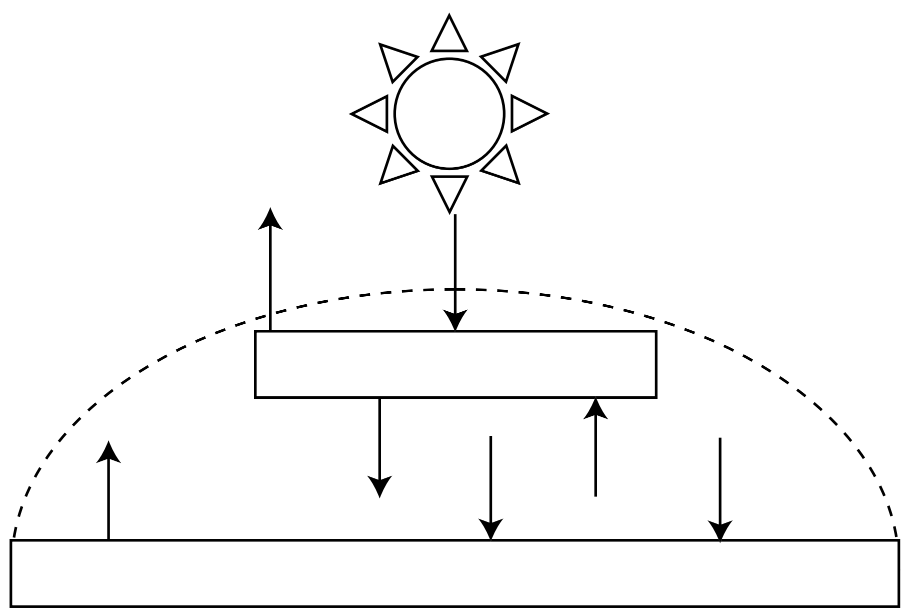


Figure 4.5. Energy budget simulation of a sun/planet system where the planet has an atmosphere with only nitrogen and oxygen.

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

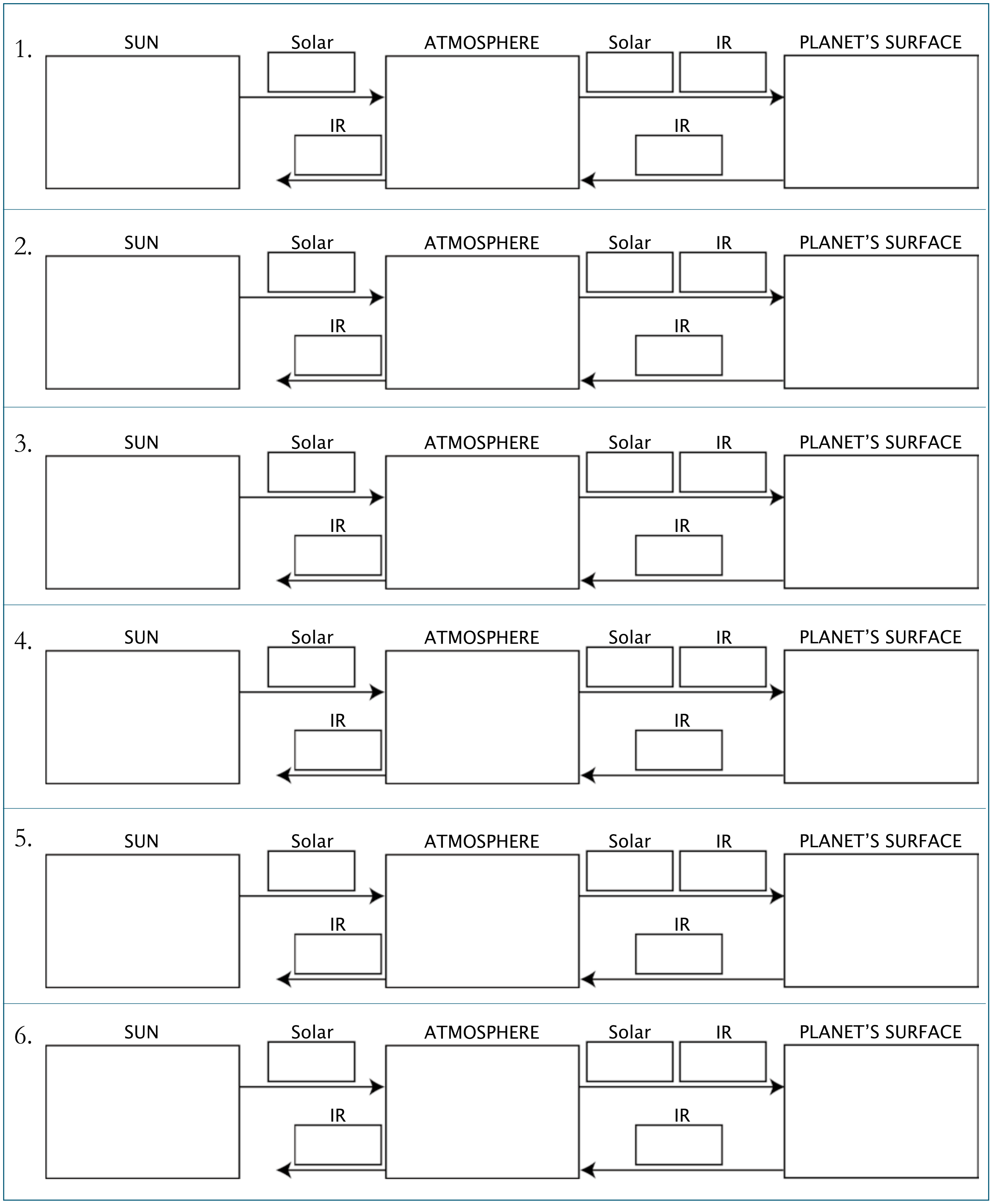


Table 4.6. Energy budget simulation of a sun/planet system in which the planet has an atmosphere with only nitrogen and oxygen.

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?

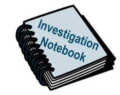
2. What happens to the solar energy that arrives at the planet's surface?

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.

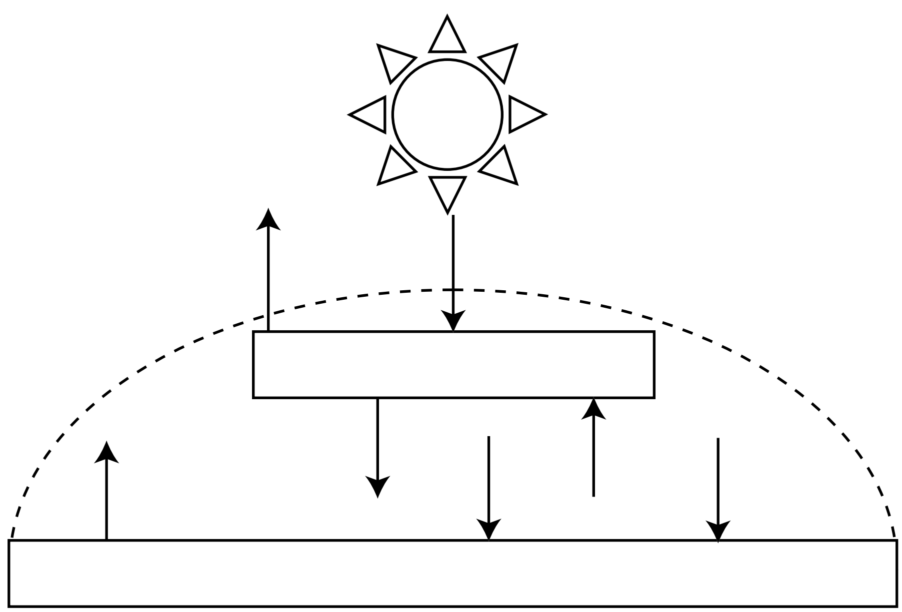


Figure 4.6. Energy budget simulation of a sun/planet system where the planet has an atmosphere with nitrogen, oxygen, water vapor and carbon dioxide.

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

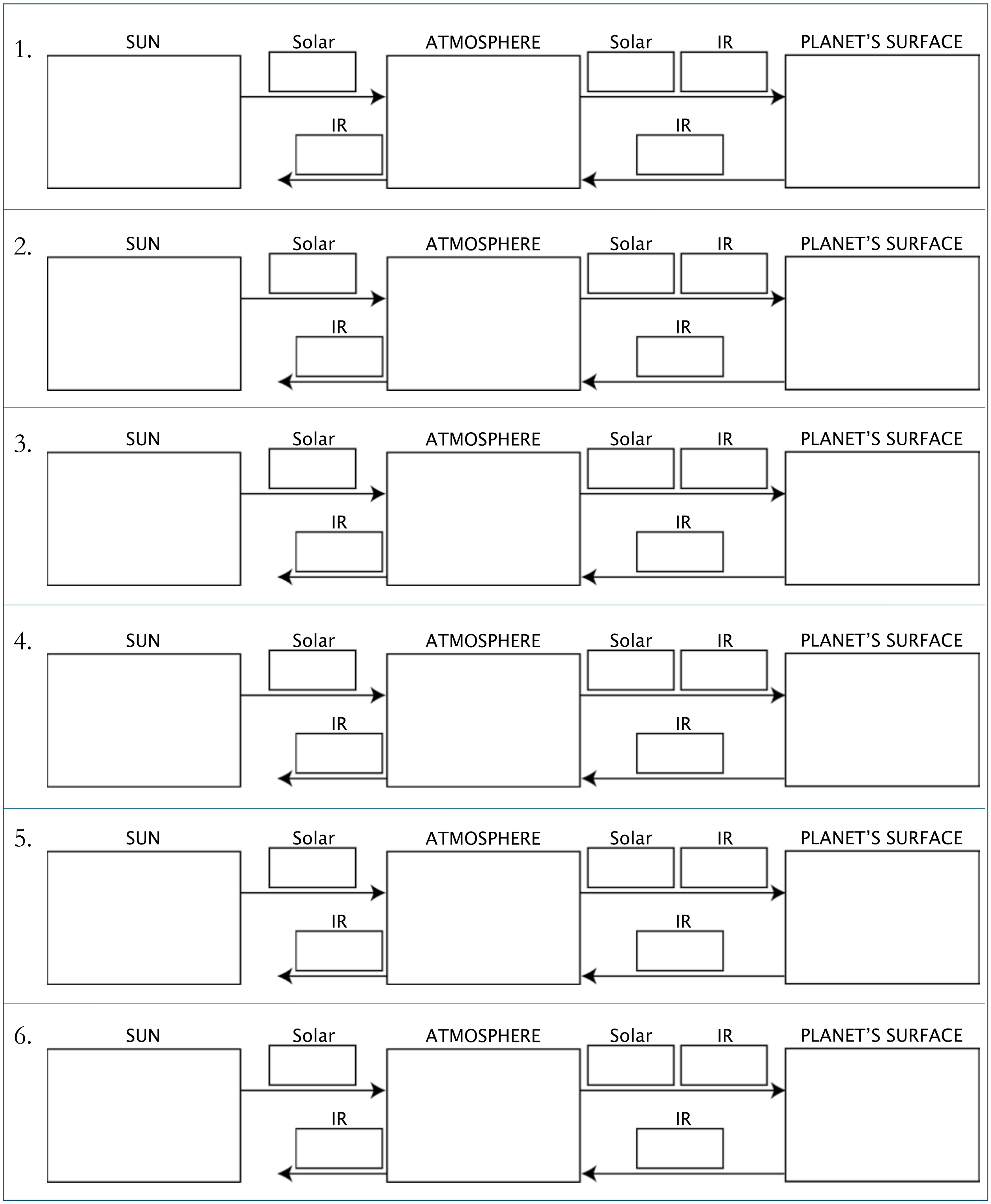


Table 4.7. Energy budget simulation of a sun/planet system in which the planet has an atmosphere consisting of nitrogen, oxygen, water vapor and carbon dioxide.

Questions Activity B

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.

Investigation Activity C

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

Investigation Notebook

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.

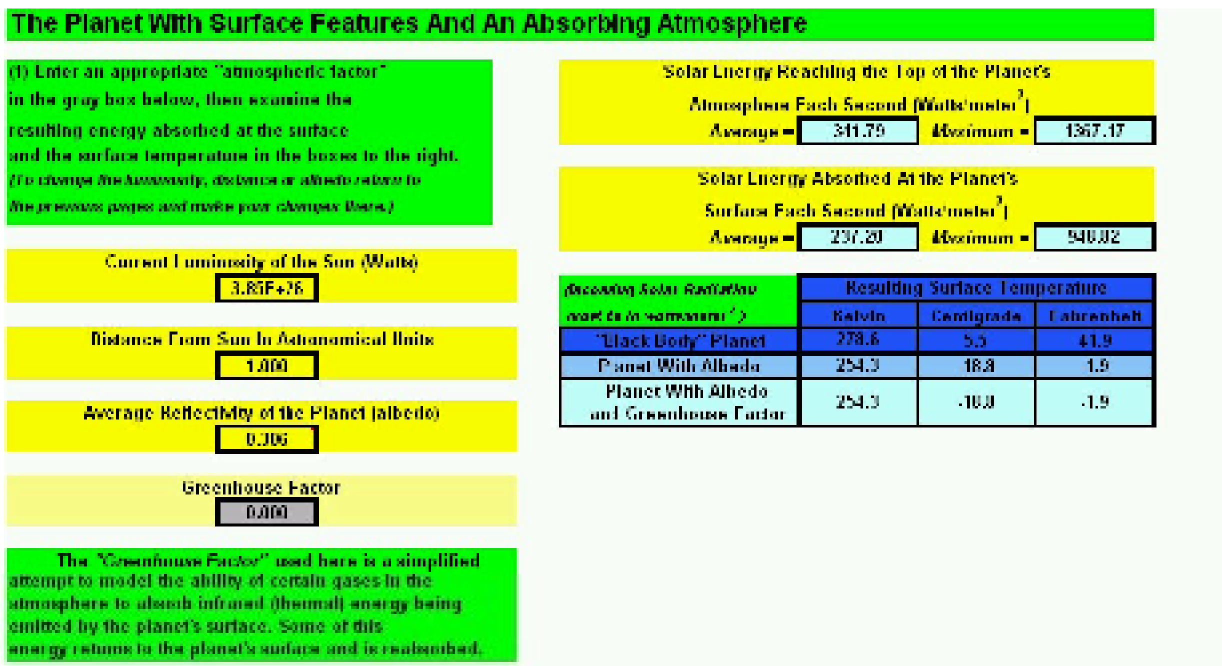


Figure 4.7. Screenshot of page 3 of the mini-GEEBITT, Version B spreadsheet model. The greenhouse factor appears in the first column with its default value 0.000 displayed in a gray-colored cell.

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.

Investigation Activity D

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?

Data Sheet Activity D

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?

Essay Topic 4

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.

Institute on Climate and Planets
NASA Goddard Institute for Space Studies
2880 Broadway
New York, NY 10025

http://icp.giss.nasa.gov