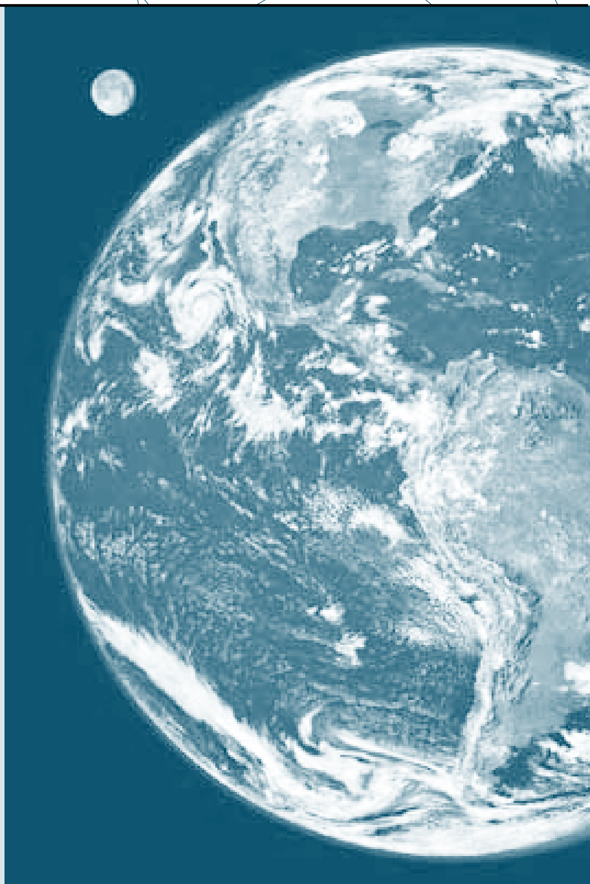
What Determines a Planet's Climate?



TEACHER NOTES

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

To The Teacher

In order to make connections between science and education that can impact how science is taught and learned, a collaborative program at the NASA Goddard Institute for Space Studies was created to involve climate researchers, students, and teachers in the Institute on Climate and Planets (ICP). It is designed to foster joint investigations concerning actual research problems related to climate change and to enhance classroom learning and teaching with lessons motivated by this educational experience. '*What Determines a Planet's Climate?*' is a major project of the ICP. We also attempt to help interpret and implement national and state science standards by tying them to curricula based on research and scientific thinking skills in what we call *Research Education*.

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.

Lead Writers and Developers

Christopher Petersen, A. Philip Randolph Campus High School
George Tselioudis, Columbia University

Writing and Development Team

Carolyn Harris, Earth Institute at Columbia University
Latika Keegan, SGT, Inc.
Andrew Lacis, NASA Goddard Institute for Space Studies
Anthony Del Genio, NASA Goddard Institute for Space Studies
Robert Schmunk, NASA Goddard Institute for Space Studies
Robert Kruckeberg, A. Philip Randolph High School
Patrick Cushing, New Rochelle High School
Samuel Borenstein, York College, City University of New York
Colin Price, University of Tel Aviv

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

http://icp.giss.nasa.gov

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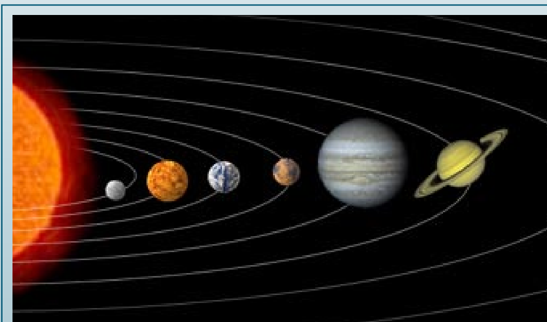
Introduction

About 'What Determines a Planet's Climate?'

This module is designed to connect cutting edge NASA research with the teaching and learning of core science and mathematics concepts and skills while addressing state and national education standards. Since an important goal of research is creating new knowledge, the process of science inquiry and the research tools used to do research play a major role in all the lessons. Presented with a science problem, students seek answers and consensus by experimenting with physical and computer models, collecting and analyzing their own measurements, and conducting intercomparisons with real world data from satellites and ground-based observations.

NASA missions and related Earth and Space Science topics provide the real world problem context for student investigations. An important aim is for students to develop a scientific view that our environment is a system of human and natural processes that result in changes over various space and time scales. The authentic science experiences presented in this module are meant to develop life-long skills for thinking critically about a science problem and applying tools of science inquiry in new learning situations. This approach to learning and teaching considers the capacities students will need to develop in a workforce and society where science, technology, and public issues are increasingly connected.

What determines a planet's climate?



What is the relationship between planetary temperature and distance from the sun?

The Science Research Context and Questions

What are some of the important factors that help regulate the balance of incoming and outgoing solar radiation? What is their role in creating an energy budget for Earth that produces habitable temperatures around significant portions of our planet where people live? How do these climate conditions compare to our neighboring planets Venus and Mars?

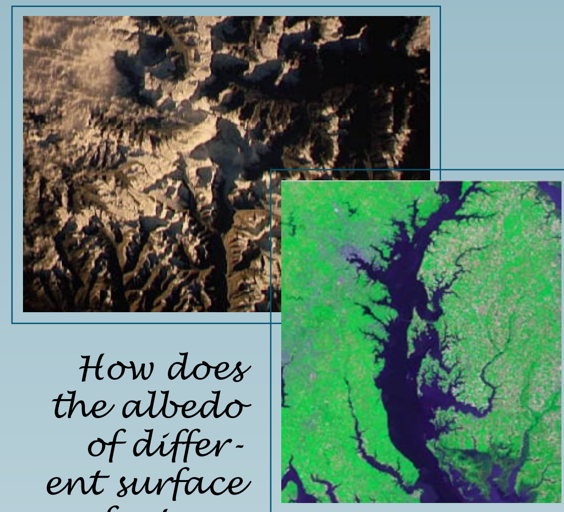
From space, we see Earth as a planet covered largely by blue oceans and white clouds. As the Earth orbits around this bright star, the sun emits enough energy to the planet to change the coolness of the night into the warming of the day around the globe. If we observe our planet from this vantage point for the length of year, we begin to appreciate the global influence of the sun

Moving in for a closer look, we pass through layers of air in motion around the globe. Soon diverse surface features are visible revealing regions of deserts, ice and snow, mountains, rivers and lakes, and forests and other vegetation.

Nearing Earth's surface, evidence of human development on our planet's land surface can be found in patterns of city skylines, suburban sprawl, agricultural clearings, industrial complexes, and road systems.

Making similar direct observations of the human and natural influences on Earth's atmospheric composition is not as easy. We are able to detect the haze that can blanket heavily populated cities from gases emitted from power plants, automobiles and industrial facilities. In rural communities, a comparable dense haze can develop from dust or fires associated with clearing the land for farming.

The research context and questions guiding this module help students develop an understanding of the human and natural factors that influence the composition of Earth's atmosphere and the reflectivity (albedo) of its surfaces. It engages students in an investigative process to learn how these factors help regulate Earth's energy budget. They discover how some factors warm Earth's climate by absorbing the sun's radiation while others produce a cooling effect by reflecting energy away from the planet. When they conclude with an examination of the greenhouse effect, students can draw upon the knowledge they develop in this module to begin to construct a system-level understanding of Earth's climate.



How does the albedo of different surface features influence planetary temperature?

How do natural and human factors contribute to planetary temperature?

How does the greenhouse effect produce a habitable Earth temperature?

Topic 1: Temperature Variations and Habitability. Students gain a perspective of the magnitude and range of temperatures that exist in diverse geographic locations on Earth and neighboring planets in our solar system. Hypotheses are formulated about factors that influence temperature, relationships between "inputs" and "outputs" in the Earth system that affect temperature and human- and natural-induced modifications in this system. These hypotheses will be the basis for students to design physical models and experiments for more in-depth studies of planetary temperature in Topic 2.

Real World Problem: Searching for Life in Extreme Environments.

Initially, students investigate their immediate environment, proposing and collecting measurements with a variety of meteorological instruments to quantify their descriptions of indoor and outdoor conditions. Temperature data analysis and comparative studies are conducted on several planetary scales from the local environment to extreme regions on Earth to the nearby planets of Venus and Mars. This leads to an assessment of the magnitude and range of temperature variations that influence planetary habitability.

Topic 2: Modeling Hot and Cold Planets. Students use a range of laboratory materials to construct planetary models and perform experiments to assess system behavior of variables such as distance from an energy source, and surface and atmospheric characteristics in producing planetary warming or cooling. This gives students a chance to evaluate the hypotheses they made in Topic 1 and to reject or defend their scientific claims. Independent and dependent variables are defined in each experiment, data is collected, graphed by hand and in a computer spreadsheet program, and analyzed for the importance of variables in influencing planetary temperature. A computer modeling experiment simulates the physical experiment, leading to a discussion of the strengths and weaknesses of both tools.

Real World Problem: Preparing for Mars Living in an Arctic Outpost.

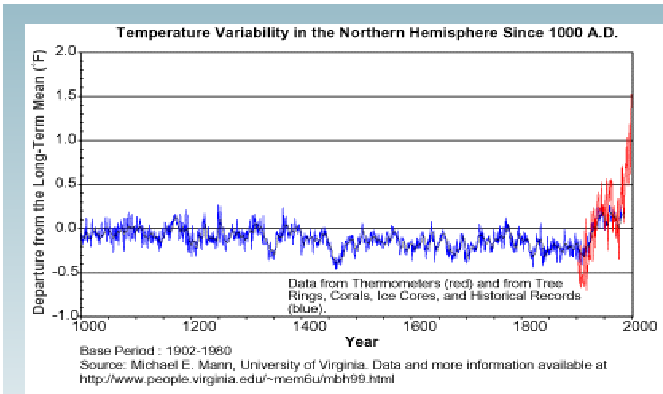
Students gain a conceptual understanding of how equilibrium temperature and surface reflectivity are related, leading into the scientific ideas of Radiation, the Inverse Square Law and the Law of Conservation of Energy. By using a global temperature data set from the Internet, students derive a value for Earth's average temperature. In the process, they acquire an introductory understanding about ground instrument networks and satellite observing techniques. They develop an appreciation for the quantity of average planetary temperature and accrue experiences dealing with data sampling and uncertainty associated with quantifying global climate.

Real World Problem: Deforestation and Urban Heat Islands.

Topic 3: Using Mathematical Models to Investigate Planetary Habitability. Building on the conceptual understandings developed in Topic 2, students conduct another round of experiments using their physical planetary models to derive a mathematical description (equation) of the relationship between 1) sun distance and intensity of light reaching a planet surface, and 2) sun distance and surface temperature. The power of the computer spreadsheet is demonstrated when students plot their experimental data collected and find the "best fit" trendline (linear and non-linear). By generating the equation of the curve that best fits the data, students can derive the Inverse Square Law.

Provided with values for the luminosity of the sun and the solar constant, students produce their own computer model in a spreadsheet program to determine the incident energy and resulting surface temperature of a planet in our solar system. Theoretical black body temperatures of Venus, Earth, and Mars are calculated. A more complex model is introduced where students input regional albedo values (a measure of the amount of incoming energy reflected by a surface) obtained from NASA satellites to determine the average albedo of Earth and to study factors that influence planetary albedo on Venus, Earth, and Mars. Acting as scientific researchers, students use actual observations in the iterative process of model development and apply modeling tools to study relationships in Earth's climate system. By the end of Topic 3, students will have compared planetary black body, average surface albedo, and actual planetary temperatures, setting the stage for considering atmospheric effects in Topic 4.

Topic 4: How Do Atmospheres Affect Planetary Temperatures? Learning activities in this final topic are designed as a synthesis of student skills and understandings. A series of developmental projects help students explain the greenhouse effect and its contribution to planetary surface temperature.



Real World Problem: Culprits of Climate Warming and Cooling.

Initially, students conduct a literature review to gain background knowledge on characteristics of the atmospheres of Earth, Mercury, Venus, and Mars.

By comparing the effect of incident heat/energy on air versus the greenhouse gas carbon dioxide in a lab experiment, they formulate ideas and make predictions about the greenhouse effect. This leads to more in-depth knowledge about the ability of atmospheric gases to trap infrared radiation in the planet's atmosphere and the influence of this physical process on the planetary temperatures on Earth, Mercury, Venus, and Mars. Specific interactions between atmospheric gases (nitrogen, oxygen, carbon dioxide, and water vapor) and incoming and outgoing electromagnetic wave energy are the focus of a classroom simulation. By tracking energy inputs and outputs, energy budgets for three sun-planet systems are calculated.

Climate modeling activities give students a chance to test their greenhouse factor predictions and study the relative effectiveness of different variables in simulating the planetary temperatures on Venus, Earth, Mercury, and Mars. Magnitudes of derived theoretical values are compared to the observations from NASA missions. In another suite of modeling experiments they terra-form Venus and Mars by varying the four main factors investigated in this module – luminosity, distance from an energy source, albedo, and the greenhouse effect. Climate modeling scenarios are presented, debated, and defended.

Education Approach, and Science, Mathematics, and Technology Standards Addressed

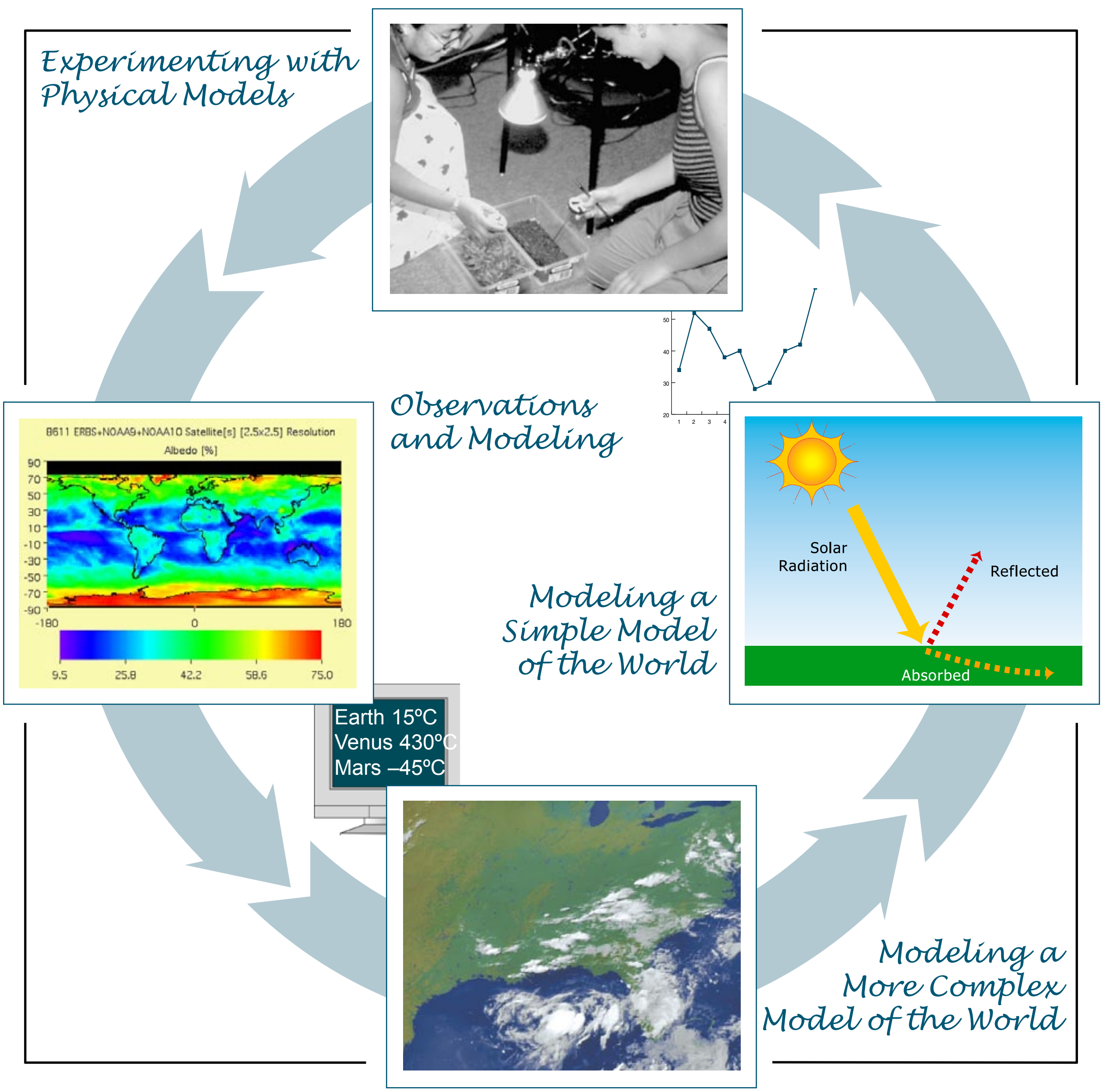
The current American science education reform movement advocates *Science For All Americans*. National education goals have created new benchmarks to prepare students with science literacy and habits that they can practically apply and that connect science, society, and technology.

The National Council on Science has recognized that there are a number of common themes that cut across all science disciplines that help organize ideas and guide scientific inquiry. These themes are integrated into *What Determines A Planet's Climate?*, and include systems, models (physical, conceptual, and mathematical), stability and equilibrium, conservation, symmetry, patterns of change (trends, cycles, and chaos), evolution (possibilities, rates, and interactions), and magnitude and scale (AAAS, 1990). They also serve to organize science content into a structured body of knowledge that stands to make more sense to novice students, who can be easily turned off by scientific content because it often appears as a jumble of disconnected facts.

This course module addresses national science standards cited by the American Association for the Advancement of Science in *Project 2061* and by the National Research Council in *National Science Standards*, as well as the New York State *Science, Mathematics, and Technology Standards*. Many problems presented require reasoning about relationships between variables interacting in the Earth system. Students have a chance to develop hypotheses about these relationships and test them in experiments that develop their current understandings about how the world works.

Their analysis and interpretation draws on their own experimental data, as well data from NASA satellites and ground-based instruments. In the process, they evaluate the strengths and weaknesses of measurements. Various scientific tools are employed by students to design and perform experiments that develop understandings about the Earth system's physical setting and living environment. This involves using both physical and computer modeling techniques. The computer models are particularly helpful in visualizing and evaluating physical processes.

Science concepts are learned through research where students build consensus about science results and prepare a synthesis of how they apply to over arching questions of relevance to science and society. In sum, the problems presented in this module translate many goals of science reform into a practical model, encompassing studies that are interdisciplinary, systemic, real-world problems, inquiry-driven, and thematically connected to the science, mathematics, and technology our students study. By giving students real scientific roles as NASA climate researchers, students can learn science by *doing* science.



Organization of the Module

There are four main topics, each introduced by a Real World Problem. These Real World problems serve as an introduction to each topic and should be read by the students and discussed briefly before they begin the first activity. After completing all the activities in the topic, the students are asked to return to the Real World Problem and answer it from their new perspective.

Topic 1 gives students a chance to summarize their current understandings about factors influencing planetary temperature.

In Topic 2, they conduct experiments with physical and very basic computer models to build conceptual or qualitative understanding of relationships among selected variables that contribute to temperature of a planet.

By Topic 3, students are involved in quantifying these relationships with more advanced computer modeling tools.

The module concludes with Topic 4, introducing students to a more complex, quantitative system understanding of how energy interacts with surface and atmospheric characteristics to produce a planetary energy budget and greenhouse effect.

Science content background and skills are addressed in each topic through a series of investigations. They begin with a suggestion for how to engage students in a discussion about the relevance of the investigations and define their existing perceptions. Most topics have an activity where preliminary discussion and investigation planning can take place. While guidelines for the investigation procedures are provided, students are often asked to design some or all of the experimental tasks and roles. Data Sheets are included for them to record observations and data analysis. After completing the investigation, the class discusses their results and develops a consensus about what they have learned in the context of a suggested guiding question related to the topic's real world problem. Their interpretations and understandings of the science results are documented on pages titled Investigation Questions. The Investigation Questions and an Essay at the conclusion of each topic give students a chance for synthesis and assessment of what they have learned. The formats include multiple-choice questions dealing with key science concepts, constructed responses to explain how a physical process works and an essay to apply this knowledge to a problem. References are provided as resources for investigations and assessment questions.

Evaluation of Student Work

At the end of each topic, a guide to evaluating student learning is provided. Investigation questions for each activity are followed by brief explanations of what to look for in their answers. These should be used in conjunction with the Learning Objectives listed in each activity to evaluate the understanding of science concepts.

Syllabus

Topic 1: Temperature Variations and Habitability

Activity	Learning Objectives	Science Skills
Real World Problem: Searching for Life in Extreme Environments	Self-assessment of students' knowledge of the habitability of environments. Research based essay addressing the consequences of changing the factors that make the earth habitable.	Locate sources of pertinent information. Evaluate data from sources. Make inferences from selected data.
A: Observing, Describing and Adapting to Environmental Variations	Identify five factors useful in describing local environmental conditions. State the range of temperature variability on the earth and in the solar system. Relate the quality of life on Earth to temperature variability and our environment.	Observe and measure temperature and other characteristics of weather. Compare values and identify sources of differences. Identify ranges of variability. Make hypotheses based on observed trends.
B: Relating Factors that Influence Planetary Temperature and Habitability	Give three examples of how humans modify the environment to improve livability. Identify three factors that can determine the average temperature of a planet. Identify five factors that may determine the habitability of a planet. State the importance of maintaining habitable temperatures on a planet. Describe the links between two factors.	Make observations of one's surroundings. Organize information logically. Explain the connection between related concepts. Work with a team to form a consensus. Communicate conclusions to others. Evaluate the conclusions of others.

Topic 2: Modeling Hot and Cold Planets

Activity	Learning Objectives	Science Skills
Real World Problem: Preparing for Mars Living in an Arctic Outpost	Evaluate the selection of Haughton Crater as a simulation of Mars. Apply concepts learned to describe facilities needed to make the site habitable.	Analyze and critique scientific hypotheses as to their strength and weaknesses.
A: Modeling Hot and Cold Planets	Design an experiment to answer a specific question and test a hypothesis. Differentiate between independent and dependent variables. Evaluate results and suggest modifications to an experiment. Prepare a synthesis of the experimental results to prioritize a set of parameters. Explain a conceptual relationship among temperature, energy inputs, surface features. Describe the strengths and limitations of physical models.	Develop testable hypotheses. Plan and implement investigative procedures. Select equipment and technology appropriate for the investigation. Share duties with team members. Collect data. Organize and analyze data. Present results clearly and logically. Evaluate experiment results of others.
B: Experimenting With Computer Models	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 a body. Describe the strengths and weaknesses of computer models.	Use a computer model to simulate real world phenomena. Design and perform experiments with a computer model. Organize and analyze data. Evaluate the effectiveness of a computer model in simulating real world phenomena. Analyze the effect of changes on a system in equilibrium.
C: Approximating the Average Surface Temperature of the Earth (optional)	Utilize a data source from the Internet. Determine average temperature of Earth. Specify the characteristics of a sampling necessary to achieve an accurate average.	Find an appropriate source of data not easily obtained in a laboratory. Select a random set of values to determine an average. Evaluate the amount of data needed to achieve a reliable result.

Topic 3: Using Mathematical Models to Investigate Planetary Habitability

Activity	Learning Objectives	Science Skills
Real World Problem: Deforestation and Urban Heat Islands	Describe how humanity can change the albedo of the earth. Describe how these changes may effect global and local temperatures.	Evaluate the effect of humanity on the environment. Draw inferences based on data.
A: Finding a Mathematical Description of a Physical Relationship	Make measurements with a voltmeter. Produce a graph using a spreadsheet. Determine the best fit for data using a spreadsheet. Quantitatively relate distance from the source to the energy incident upon a body. Quantitatively relate temperature of a body to the distance from a source of energy. Use the derived relationships to predict observed values.	Develop testable hypotheses. Plan and implement investigative procedures. Share duties between members of a team. Collect data and make measurements with precision. Use observed data to find a mathematical relationship between the variables.
B: Making a Simple Mathematical Model	Make an Excel spreadsheet model to determine the temperature of an object given its distance from an energy source. Compare theoretical black body and observed temperatures for a planet. Describe three advantages to using mathematical models. Describe three disadvantages to the use of mathematical models.	Use a variety of tools to analyze data. Use relationships observed in a system to model that system. Make predictions based on the model. Evaluate the effectiveness of the model. Determine the type of model appropriate for an investigation.
C: The Role of Actual Data in Mathematical Models	Read and analyze an albedo map of the earth. Determine the average albedo of the earth. Utilize the GEEBITT spreadsheet model. Compare theoretical and observed gray body temperatures for a planet. Suggest further improvements to the spreadsheet models.	Evaluate and make inferences from a data set. Use real world observations to modify a model. Evaluate the modifications of the model.

Topic 4: How do Atmospheres Affect Planetary Temperatures?

Activity	Learning Objectives	Science Skills
Real World Problem: Culprits of Climate Warming and Cooling	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.	Synthesize data from various sources to determine significant relationships in terms of magnitude and scale Develop scientific claims that can be supported in research results State claims in a context that can be understood by the public and policymakers
A: How do Atmospheres Interact with Solar Energy?	State that an atmosphere has an overall warming effect upon a planet. Describe the major characteristics of the atmospheres of Venus, Earth, and Mars. State that the magnitude of the warming effect depends upon specific characteristics of the atmosphere. Observe and measure the temperature changes of gases exposed to light. Identify this warming ability of the atmosphere as the Greenhouse Effect. Briefly describe how an atmosphere produces the Greenhouse Effect.	Compare real world and model observations in order to make hypotheses about the real world problem. Perform a literature (library and/or Internet) search to determine the current state of knowledge about a science concept. Make observations and collect data from a physical experiment. Relate the results of the experiment to the previously made hypotheses. Describe key science concepts in one's own words. Come to a preliminary consensus with other investigators as to the best explanation for a physical phenomenon.
B: How do Atmospheres Produce their Effect Upon Surface Temperatures?	Describe the effect of nitrogen and oxygen in the Earth's atmosphere on incoming and outgoing electromagnetic waves. Describe the effect of carbon dioxide and water vapor in the Earth's atmosphere on incoming and outgoing electromagnetic waves. Define "greenhouse gas" and explain its effect on the surface temperature of a planet.	Make observation and collect data from a simulation. Relate the results of the simulation to real world phenomena. Relate the characteristics of electromagnetic waves to their properties. Modify a description of a phenomenon based upon new knowledge.

C: Can we Model an Atmosphere's Effect Upon a Planet's Surface Temperature?	Use the characteristics of a planet's atmosphere to estimate the magnitude of the Greenhouse Factor for 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.	Use a mathematical model to simulate real world conditions. Use the experimental results of the mathematical model to make hypotheses about the real world. Use real world observations to evaluate these hypotheses. Come to a consensus with other investigators as to which hypothesis is the best so far.
D: Can Venus and Mars Be Made Habitable?	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 feasibility of terraforming Mars and Venus. Relate the knowledge obtained in this module to the quality of humanity's future on the Earth.	Plan and implement an investigation using a mathematical model. Collect data and make measurements with care. Propose a feasible solution to a real world based upon a model simulation. Defend the solution with logical and science based arguments.

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**

Topic 1

Temperature Variations and Habitability

Overview

To understand why Earth is hospitable to life, it is important to study the conditions that contribute to a planet's habitability. We can begin by looking at the kinds of adjustments humans make to produce more comfortable living environments. Temperature is one of the most basic conditions that we adjust. Topic 1 is an introduction to the module, providing an appreciation of temperature variations that exist on Earth and our neighboring planets, and a sense of some factors that influence average planetary temperatures.

Science Content

Temperature variations on Earth and our neighboring planets

An initial idea of the importance of temperature in planetary habitability can be gained by identifying the magnitude and range of temperature differences found on neighboring planets, Mars and Venus, as well as in diverse geographic locations on our own planet. By comparing images of planetary surface and atmospheric features, we can begin to formulate hypotheses for factors that produce an average planetary temperature that is habitable. Evaluating the relative importance of these factors helps in identifying variable ranges needed for habitability. Relationships between these system variables and ways humans and nature influence planetary temperature have positive or negative consequences on Earth's habitability.

Science Skills

Measurement and experimental design

To appreciate how humans can modify the environment, students participate in an exercise to describe and compare differences between conditions inside and outside the school building. Students will propose measurements needed to quantify their statements and a plan for collecting data. In making observations of indoor and outdoor environments using science instruments, the value and limitations of these tools can be appreciated.

Data analysis and magnitude and scale

Data analysis of temperature and environmental conditions is conducted on various planetary-level spatial scales. First, students study environmental conditions in their own local environment. Next, they look at the temperature and surface features in the Sahara Desert and Antarctica. Their final task is to study the average planetary temperatures of Venus, Mars, and Earth, and images of their planetary and surface features. A comparison of these data leads students to assess the magnitude and range of temperature variations that influence habitability.

Knowledge mapping, systems thinking, and hypothesis development

With an initial idea about the factors that determine a planet's habitability students can hypothesize about relationships among these system variables. By connecting the variables where they believe a relationship exists and preparing justifications for these connections, students can develop a "knowledge map" that diagrams "inputs", "variables," and "outputs" in the earth system that help determine average planetary temperature.

Considering a Real World Problem

Searching for Life in Extreme Environments

A wide range of environmental conditions characterizes regions around the globe. In Topic 1, students offer their ideas on the factors or conditions that make our planet habitable and explore the range of temperatures that exist on Earth and neighboring planets in our solar system. The real world problem asks them to apply their initial understandings to consider the most extreme environments on Earth where life forms exist, such as the geysers and hot springs in Yellowstone National Park where microorganisms live and grow.

Students offer their perspectives on the magnitude of differences in environmental conditions where humans can exist, as well as 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. The ideas they formulate provide the basis for hypotheses and experiments students will develop in Topic 2 to test the influence of various factors on planetary temperature.

Activity A

Observing, Describing, and Adapting to Environmental Variations

1 class period

What do students understand about the range of temperatures found on the Earth and within the solar system? Begin by asking students, "What would we have to do to make areas with extreme temperatures more comfortable for humans?" The first activity is to compare indoor and outdoor conditions where students live. After some discussion, they hypothesize about what kind of adjustments would have to be made in order for a classroom to be comfortable in the Antarctic and in the Sahara. A variety of answers are proposed. The References at the end of the activity provide visuals of regions on Earth and in our solar system that can be used to stimulate discussion.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ Identify a minimum of five factors useful for 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.

Materials

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

Engagement

The teacher asks class how they would describe what kind of day it is. After a variety of responses, ask how students would make measurements to quantify their statements. What tools would they need? How long would it take? The class makes a plan to describe the day.

Procedure

Once the plan is formulated, students are provided with the equipment they have requested. This should include thermometers, barometers, and anemometers. The class is divided into teams, half the teams will evaluate conditions outside the building and the other half will evaluate conditions inside the classroom. Students spend about 15 minutes making observations and specific measurements. Observations are recorded on the Data Sheet provided for the activity.

Consensus

Students are asked to compare interior and exterior conditions. How are they different or similar? Discuss why these differences and similarities occur. Look at the magnitude of the differences. Answers will depend upon the season and geographic location.

How do humans modify their own environment to make it more livable? Place some emphasis upon heating and sources of energy so these concepts can be referred to later. What are alternate sources of energy? Is this done for comfort or necessity? How would these answers differ if it were some other season or another place on the earth? The teacher displays the Reference viewgraphs of sites in the Sahara and the Antarctic to elicit student responses.

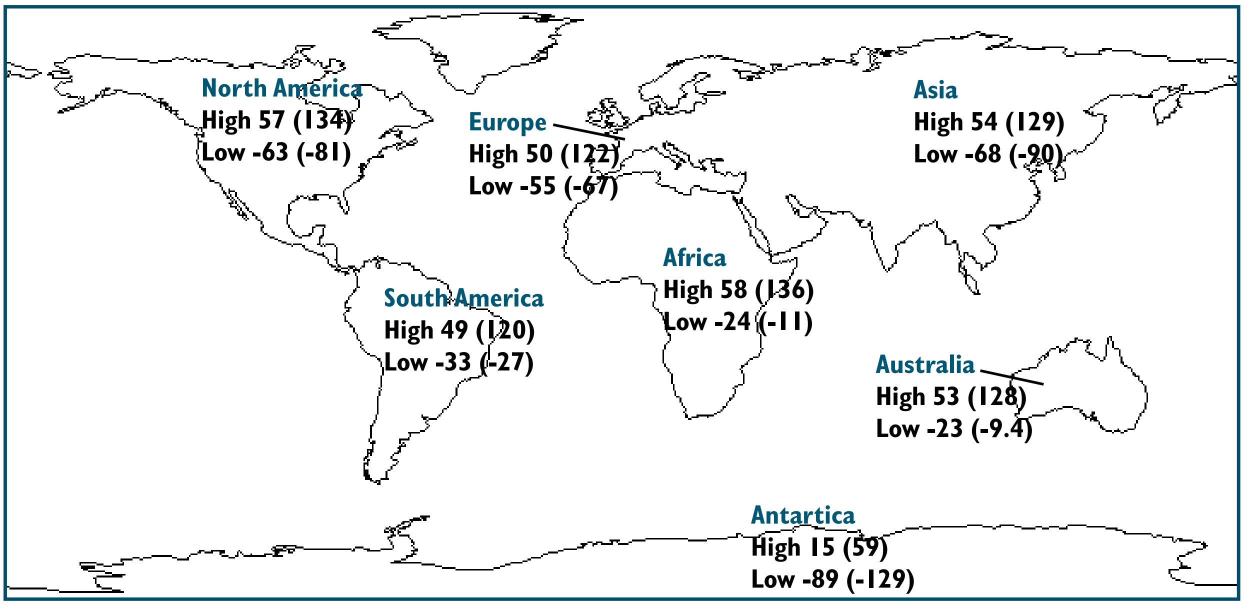


Figure 1.1. Global Measured Temperature Extremes [in ° Celsius (° Fahrenheit)].

Teacher Proposes

What if this activity were to be moved to another planet? What would we have to do to duplicate this activity on another planet? Would it be as easy as going to the South Pole? The Sahara? Show the Reference viewgraph of the earth and ask the class to think about the following question: What makes the earth so special to humans? Teacher elicits answers from students to obtain a general answer.

Synthesis

The Reference viewgraphs of other planets are shown to emphasize the hostile environments present in the solar system. A summary of these comparisons would be the last Reference viewgraph shown. Students complete the investigation's Questions prior to discussing conclusions about the range of temperatures that exist on Earth and within our solar system, and ideas about the relationship to the habitability of these environments.

Activity B

Relating Factors that Influence Planetary Temperature and Habitability

2 class periods

This activity enables the teacher to ascertain students' understanding of factors that determine the average temperature and habitability of planets in general and the earth in particular. By developing diagrams called "Knowledge Maps," students convey their ideas about the essential factors needed to produce a habitable temperature, including links between related factors. Knowledge Maps are tools to help students formulate testable hypotheses. Explaining and defending the maps is a key part of this activity. The hypotheses developed will drive the process for students to design experiments in Topic 2 concerning the relative significance of their factors.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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 their choosing.

Materials

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

Engagement

Class Period 1

Present an example of a knowledge map dealing with a familiar topic, such as factors influencing a flower's growth. This will help students produce a *Habitable Planetary Temperature Knowledge Map*.

Procedure

Students work on teams of about five members each. The initial task is to construct a Knowledge Map of the essential ingredients or factors for a habitable planetary temperature. Each team selects a recorder. A list of approximately 10 essential factors is prepared, with each factor written on a separate Post-it note. On poster paper, students group the most closely related factors, using colored linking strips to show strong relationships. They should be prepared to explain why they chose their factors, how they are related, and how they contribute to planetary habitability. These ideas should be discussed within the team and brief summaries of explanations recorded. The teacher circulates to ensure student efforts in this direction.

Class Period 2

Habitable Planetary Temperature Knowledge Maps are presented. Questioners and Presenters are selected among the students. Each designated Questioner selects one Knowledge Map team to examine. A team will be given time to present and explain their map and defend it in response to questions. Questioners will fill out the Knowledge Map Assessment Form for the Presenters. This process introduces different perspectives about factors needed for a habitable planetary temperature and relationships between them.

Consensus

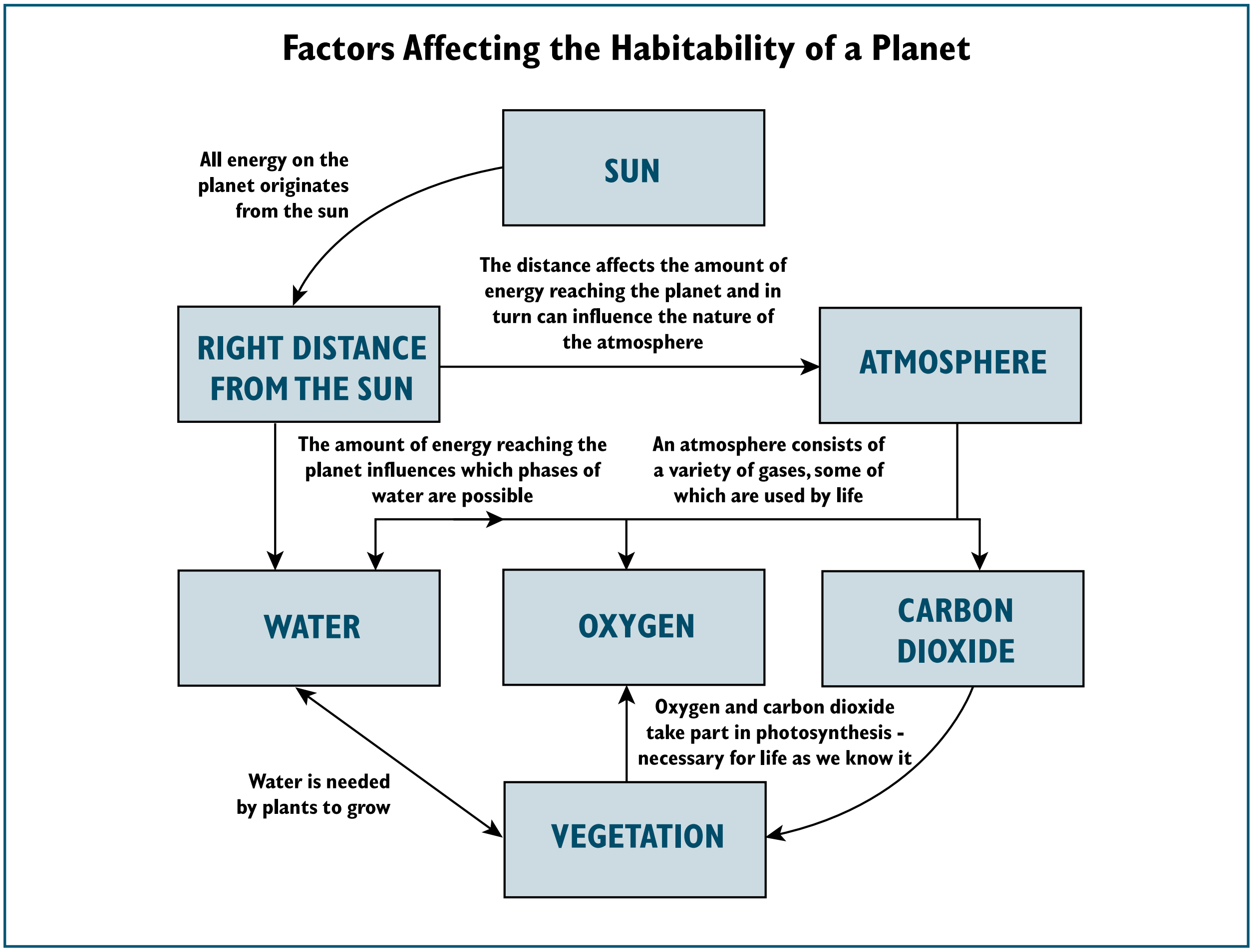


Figure 1.2. Sample Knowledge Map.

The concept of a *system* is introduced. An aquarium can be used to illustrate this idea. Ask students to identify the *inputs* (light, food, heat, air, etc.), the *variables* (amount of water, number of fish, clarity of water, etc.) and the *outputs* (reflected light, odors, sound, etc.). Students define these three concepts. A planet can be viewed as a system, albeit a large one. Students then return to their Maps and identify factors as inputs, system variables, or outputs. Each student submits a Data Sheet with their team's system diagram, including factors, links, and explanations. The Investigation Questions are also handed in to the teacher.

Synthesis

A class discussion of how all the ingredients can be classified is held, producing a class list of the inputs, system variables, and outputs of the planet as a system. Students are informed that they will use this list as a set of hypotheses to investigate the planet as a system during the next learning activities. Their final assignment is to prepare a short essay that addresses the Real World Problem: Searching for Life in Extreme Environments.

Evaluating Student Work

Topic 1. Temperature Variations and Habitability

Activity A – Investigation Questions

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

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

3. Discuss whether or not you think it would be practical to build large cities in the Sahara and/or the Antarctic?

4. 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 1.1 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.

5. What makes Earth special to humans?

Answer Guide – Questions 1 through 4

Students should discuss the fact that energy must be consumed in order to create comfortable conditions for everyday human activities, and that the amount and type of energy is different for the different regions of the globe. They should also indicate that even the largest differences between Earth regions are small compared to differences between Earth and other planets.

Answers to these questions should show that students understand that temperature is one measure of habitability, but by no means the only one. They should also make some connection with the magnitude of the temperature extremes at a point and the amount of energy or cost necessary to maintain habitable conditions.

Activity B – Investigation Questions

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

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

3. Do you think there is anywhere on Earth that is so inhospitable that human beings cannot physically visit it? Would your answer change if you were to consider the whole solar system?

Answer Guide – Questions 1 through 3

This is a knowledge assessment exercise; most logical answers are acceptable. The emphasis should be on the ability of the students to built logical links between factors and to distinguish between inputs to a system like sunlight, system properties like color of the surface, and outputs like surface temperature.

Answers should refer back to the concept diagrams that the students developed during Activity B. Acceptable answers should include direct references to the relationships discussed in the concept diagrams.

Essay: Real World Problem – Searching for Life in Extreme Environments

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.

Assignment: Write a 300 word essay that responds to the questions in this topic's Real World Problem. 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.

Minimum Expectations for this Essay

✓ State at least three conditions or factors essential to maintaining human life.

✓ Provide a short discussion on how these factors interact.

✓ Give at least two examples of extreme environments on Earth (preferably not the Sahara or the Antarctic).

✓ Give an example of the range of values for the above factors for these environments.

✓ Give two examples of life in extreme environments on Earth (e.g. black smokers in the Atlantic Ridge).

✓ Discuss the implications of the existence of these life forms upon the possible existence of life on other planets.

✓ Discuss the effect changes in at least one of these factors has on the habitability of Earth.

In the essay, students should exhibit their knowledge of the factors leading to habitable temperatures on a planet and that these factors are logically linked to one another. They should also indicate that they understand that while habitable conditions for humans exist in a somewhat narrow range of values, other life forms can exist in conditions too extreme for humans.

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

Topic 2

Modeling Hot and Cold Planets

Overview

Investigative teams are presented with a challenge to construct physical models of hot and cold planets in a way that will maximize the temperature difference between the two models. The aim is to design an experiment using physical models to evaluate the relative importance of some of the variables in a planetary system that influence average surface temperature.

Science Content

In Topic 1, several factors or variables that produce warming or cooling effects were identified. Comparing the surface and atmospheric features found on other planets in our solar system provided further evidence of these factors. Why does the average surface temperature on Venus hover around 430°C while that of Mars is approximately – 45°C? Such extremes are hardly found even in Earth's most inhospitable areas, the Sahara and the Antarctic. Earth's average surface temperature is 15ºC. How can the planets in our solar system most similar to Earth have surface temperatures so vastly different from each other or from the earth? By the end of this study, teams will theorize about the relative importance of variables that influence temperature and habitability. Discovering ways the sun's energy interacts with a planet's surface to produce an average temperature will provide students with evidence to support their hypotheses.

Science Skills

Experimental design and measurement
An experimental proposal is prepared, including design plans for planetary models, a testable hypothesis, measurement protocols, and identification of independent and dependent variables. After the first round of experiments collecting temperature data, teams evaluate and modify their model and conduct a second round of experiments.

Data analysis and mathematical reasoning
Data collected from the hot and cold planet model experiments is used to compute the change in temperature from the start to the finish of the experiment. These data are plotted to observe the behavior of the temperature over time. Team results are compared to analyze the significance of each variable in influencing temperature and to prioritize variables. Students must use experimental evidence to justify their conclusions. To clarify the concept of average surface temperature, an optional activity is provided for students to use a global temperature data set to derive a value for Earth's average surface temperature.

Systems thinking, modeling, and technology

Preparing physical models of hot and cold planets requires thinking about the system inputs, variables, and outputs that interact to produce planetary surface temperature. Each team will evaluate their model's strengths and weaknesses. Computer software is introduced for students to simulate the physical model experiment. Strengths and limitations of this computer-based model are also discussed. The optional activity requires students to calculate the average surface temperature of the earth using their data collected. The instructor can decide to ask students to calculate the average by hand, using a calculator, or by using a computer spreadsheet program such as Microsoft Excel, to record data and calculate the result.

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. Great interest in this mission has lead to a funded project to construct an experimental facility at the Haughton Crater on Devon Island, Nunavut, Canada. Here, scientists and engineers are developing and testing technical and human capabilities to live on a Mars outpost.

By the time students complete Topic 2, they will have identified and prioritized several factors that are needed to produce a habitable climate. Now they are presented with a real world problem to apply these preliminary ideas in the roles of researchers on engineering or science teams designing and constructing the Flashline Research Station to address several questions.

Is the Haughton Crater the best Earth location for an experimental Mars human habitat? What geologic and atmospheric conditions exist on Devon Island, Canada, that may have led to the decision to construct the facility here? What materials would you use to construct the habitat? How would your design produce habitable conditions for researchers to spend extended periods of time at the facility? Students will have to justify their plans and responses using evidence derived from the planetary modeling experiments they conduct in Topic 2.

Activity A

Modeling Hot and Cold Planets

4 class periods

Based on their Knowledge Maps from Topic 1, students are asked to design their own experiments to test hypothesized relationships about factors that influence planetary temperature and habitability.

A challenge is presented to the student investigative teams to design and construct models of two planets, one hot and the other cold, using a variety of materials. The aim is to produce the greatest temperature difference between these models using all the materials available. After the first round of experiments, teams reconvene to describe their findings and discuss the ramifications of their results.

A second round of experiments may be conducted after teams evaluate and redesign their experiments to improve their results. Based upon the results of all teams, students prioritize the factors tested from those with the greatest to least effect upon planetary temperature.

This activity concludes with a discussion of the strengths and limitations of physical models in describing real world phenomena and an introduction to mathematical computer models.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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.

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

Engagement

Class Period 1

Teams examine the Knowledge Maps they prepared in Topic 1 and consider which of the factors would have the greatest effect upon the temperature of a planet. After some discussion, presentations are made concerning choices and rationale. The various suggestions are listed on the board. Pose the question: How can we decide which group is right? The ensuing discussion should produce the idea to conduct an experiment to test various hypotheses. At this point the experimental challenge and competition is presented to the class.

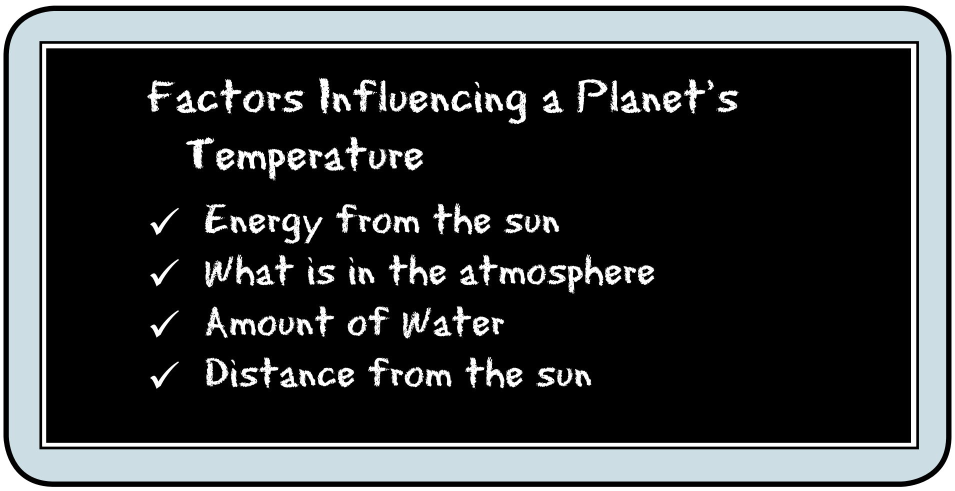


Figure 2.1. List suggestions from students on the board for factors that would have the greatest influence upon the temperature of a planet.

Procedure

Investigative teams with about five students each are organized. Each team is charged with the task of designing an experiment that tests their hypothesis about the variable with the greatest influence on planetary temperature. Before separating into teams, a brief discussion is held about what materials will be needed to conduct the experiment. This list is compared to the materials available to the class. If possible, additional materials requested by students should be added in time for the next class period.

The first two handouts, Investigation Overview and Investigation Team Members are given out so that teams can organize how their experiments will be carried out. Each team selects a Lead Researcher. There are also Materials and Data Managers and Experimental Communications roles for the hot and cold planets. An Experimental Design Proposal and Methodology for a Controlled Experiment is completed by each team.

Remind teams that the aim of the experiment is to maximize the temperature difference between their hot and cold planet models; with the constraint that only one factor can be varied between their models. All other factors must be identical.

Class Period 2

Investigative teams set up their experiments based on their proposals. The common measurement protocol for all teams is to record temperature over a 20 minute period for both the hot and cold planet models. Measurements are recorded on the Data Sheet. As the experiments are being set up and conducted, the teacher visits each team to observe procedures and answer any questions. At the end of the experiment, students complete the handout: Experimental Results. Also, it's a good idea for the teams to re-examine their Methodology for a Controlled Experiment and make any necessary revisions based on what they learn in the experiment.

Consensus

Teams reconvene to present and discuss their experimental results and suggested design improvements. The next handout is distributed, Investigative Team Consensus. Results of all the experiments are described on the board. A discussion is held to prioritize the factors affecting planetary temperature based on the results. Have teams explain their reasoning, considering the rate and magnitude of temperature change and the dependent and independent variables. The discussion should end with a consensus on the priority of factors. The handout, Priority of Experimental Parameters, should be completed at this time. Teams can conduct a second round of experiments to implement modifications they think may achieve greater temperature differences.

Figure 2.2. Setup of the experiment.

Class Period 3

Optional: Teams perform redesigned experiments and complete Investigation Questions.

Class Period 4

Synthesis

Several questions are posed and discussed. The Viewgraphs from Topic 1 can be used as a reminder of these planetary conditions.

1. What are the strengths and limitations of physical models?

2. How well do you think physical models simulate the actual temperature differences found on real cold and hot planets, in particular - Venus and Mars?

3. How well does your energy source simulate the sun's energy? Is your energy source the only source of energy in the room?

4. Why are the physical models unable to show the magnitude of difference observed between the real planets?

5. What could be changed in the physical models so that they can better mirror real planets?

6. What alternative ways of modeling are there?

Question 6 above provides a context to introduce the idea of using a computer model as a tool for understanding how a system works. See Reference: Mathematical Models.

A Word of Caution to the Teacher: If the students use the plastic wrap to cover one of the containers and observe an increase in temperature in the container be careful during the discussion that follows. The plastic wrap does behave in the same way as a blanket or the roof of a greenhouse in that all three of these stop heat from moving out from under them by preventing convection. The air beneath these objects is warmed, becomes less dense, and tries to rise, but the plastic/greenhouse roof/blanket blocks this rise and the hot air stays where it is. This is *not* however the way the atmosphere works. The atmosphere does not prevent convection, and in fact, encourages it. Certain gases in the atmosphere (the Greenhouse gases) absorb the heat emitted by the earth's surface, and in turn emit heat on their own. Some of the emitted heat is directed back towards the surface, and increases the amount of energy absorbed at the surface, warming it. While this effect is named "The Greenhouse Effect", it does not work in the same way as a greenhouse, blanket or the plastic wrap. The students will get a full explanation of the Greenhouse Effect in Topic 4, Activities A and B. At this point it would probably be best to avoid saying that the atmosphere acts like a Greenhouse to warm the earth. A better statement at this time would be "The plastic wrap causes the temperature to increase in the container. The atmosphere of some planets causes the temperature of the planet to increase, but the mechanism/process is not the same. We will learn how this works at a later time."

Activity B

Experimenting with Computer Models

3 class periods

To familiarize students with the functions of a mathematical model, computer courseware that simulates an experiment similar to the one conducted in Activity A can be used. Experiments can be run with the Radiation Balance Model found at the web site: http://icp.giss.nasa.gov/education/modules/eccm/model/. For this investigation, we are primarily concerned with Experiments 1 and 2. Experiment 3, which deals with the relationship between molecular speed and temperature is included as advanced study or an extra credit problem. Experiments 1 and 2 engage students in an investigation of the ability of an object, particularly the planetary physical model they constructed, to maintain an equilibrium temperature.

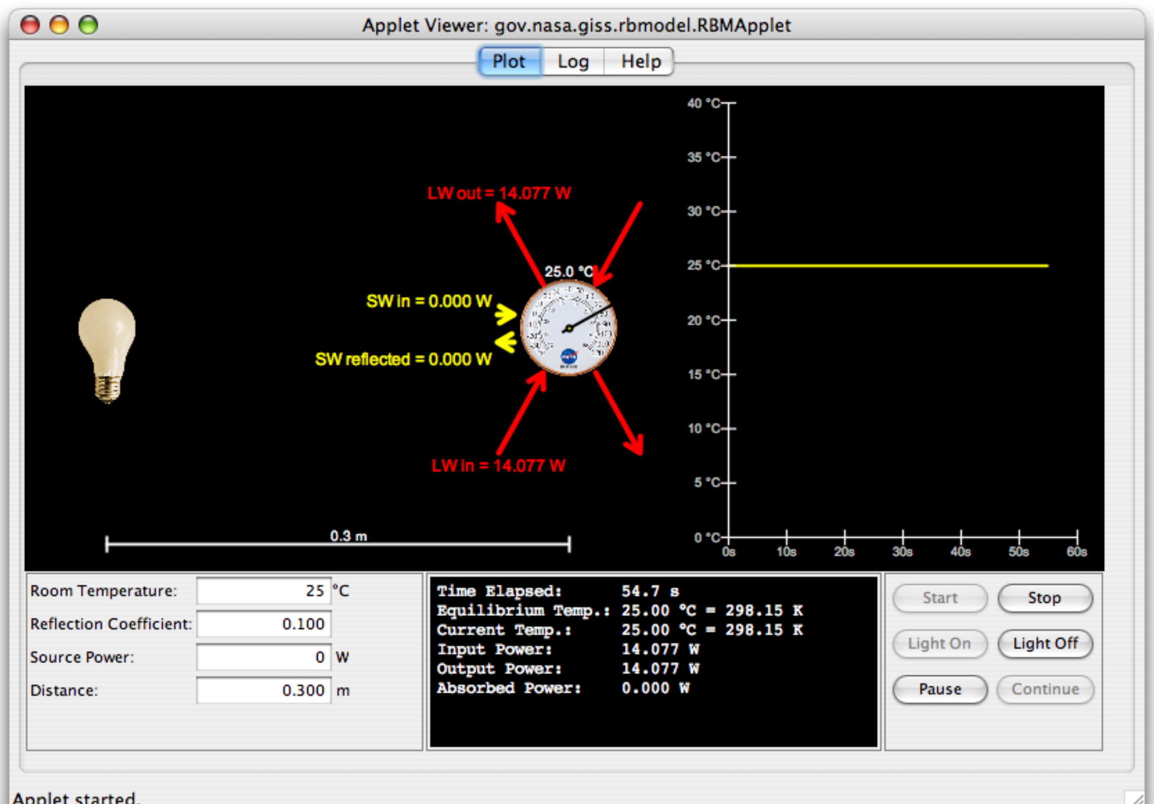


Figure 2.3. Screen shot of the Local Radiation Balance Computer Model. No energy is emitted from the source, during this experimental run, resulting in a constant temperature for the objet.

The Radiation Balance Model is a tool that can be used to examine the energy inputs and outputs of a simple system. Specifically, the simulation provides a means to study the relationships between the equilibrium temperature of an object and its distance from an energy source. It can also be used to determine how equilibrium temperature and the reflectivity of a surface are related. These relationships provide a qualitative understanding of the Inverse Square Law. (Refer to http://www2.jpl.nasa.gov/basics/bsf6-1.html for a definition of this law.)

Experimental results will enable students to discuss implications of conservation of energy and the factors that establish equilibrium temperature. The activity concludes with a comparison of physical and computer models, evaluating their strengths and limitations in simulating the conditions on Mars and Venus.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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.

Materials

Computers to run the Radiation Balance Model. It is suggested to have a maximum of two or three students per computer.

To use this model, you will need:

- ✓ A Windows or Apple based 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 from http://www.java.com/ .You will need Administrator rights for this installation.)
- ✓ 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.

Engagement

Class Period 1

Start by discussing the limitations of the physical box models that were used in the previous activity to simulate hot and cold planets. The box models were used in a room that was already warmed or cooled by a radiator or an air-conditioner. What would have happened to the box model temperatures if the room temperature was changed? Each experiment was run for a certain length of time and then the light was switched off. What would have happened to the temperature if the lights were kept on? Would the temperature keep rising?

Discuss possible outcomes (the model melts, temperature keeps going up, temperature

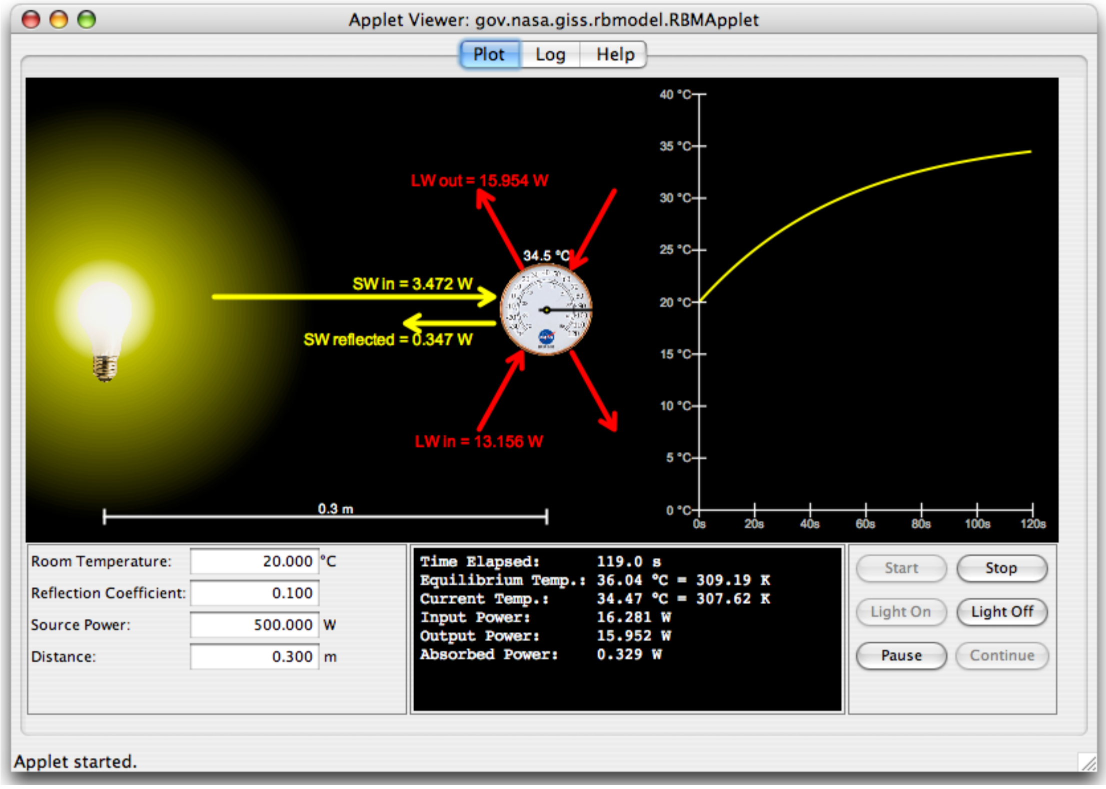


Figure 2.4. An experiment in progress using the Local Radiation Balance Computer Model.

remains constant, temperature goes up and then down, etc.). Write students' hypotheses on the board and ask them how we can determine which hypothesis is correct. A student should suggest performing the physical model experiment in Topic 1 and leaving the light on for a longer time. This is an excellent idea, however it will take too long (more than the class period) to see any meaningful results. Ask students to consider the Reference: Mathematical Models. Could such a model allow us to simulate a lengthy physical modeling experiment in a short amount of time?

Procedure

Suggestion: Conduct this class session in a computer lab. Students are introduced to the Radiation Balance Model. The Reference: Introduction to the Radiation Balance Model should be reviewed first to explain the model's features and experiments. Instead of doing the proposed experiment with the physical model, the class will use this computer simulation of the experiment to test out their hypotheses and determine the usefulness of the computer model. The model allows the student to vary the reflection coefficient (albedo) of the object, the room temperature, and the distance between the light source and object.

Divide the class into groups of two to three students each to run the Radiation Balance Model. Distribute Experiment 1: Data Sheet that provides the experimental procedure and space to record observations of the resulting "final" or equilibrium temperature. Emphasize that only one variable is being changed at a time in each experiment.

Have the different groups in class describe and compare results. They should observe that the model temperature eventually stops rising and maintains a constant temperature. Elicit hypotheses as to why this occurs. Even though energy is continually supplied to the model, the model maintains a constant temperature. By examining the graph produced by the model, the user should observe that the total energy entering the simulated object is equal to the total energy leaving it. Elicit: Why do different distances produce different equilibrium temperatures?

Please note that the Radiation Balance Model expresses its inputs and outputs in terms of power while most of the questions ask about energy. The teacher should define Power (Watts) as the amount of Work (Joules) done each second, so that a 400 Watts input would mean that 400 Joules of energy come into the system each second. When dealing with the energy questions, have the students consider the amount of energy involved each second, and that the total amount of energy increases over time.

Class Discussion

Class Period 2

Suggestion: Conduct this class session in a computer lab. Review explanations for constant temperatures of the model despite a constant supply of energy. Elicit: Can students think of other examples of equilibrium temperatures?

Possible answers:
Temperature of human body
Room temperature
Temperature of an oven while baking

In each of these cases we have a system with a source of energy (Energy Input). Have the students identify energy sources for each of these systems.

We must ask ourselves, where does the energy go? What does it do? In the case of an oven, possible answers may include that some energy goes to raising the temperature of the stove and its contents. Why do they "feel" hot to the touch? They emit energy to their surroundings because they are at a higher temperature then their surroundings. This is the energy output of our system.

Distribute Experiment 2: Data Sheet, and have groups conduct computer model simulations to study the relationship between equilibrium temperature and the reflection coefficient (albedo) and the temperature-distance relationships leading to the Inverse Square Law.

At the end of this class period, the Investigation Questions, can be assigned as homework. This will be discussed during the next class period to facilitate students reaching a consensus about what was learned.

Consensus

Because the temperature of the models (or other systems) remains constant, what must be true about the energy inputs and outputs of the system? Possible answers may include that these values must be equal. Why?

If Energy Input = Energy Output, then the temperature will remain constant.

If Energy Input > Energy Output, temperature will increase until inputs and outputs are equal.

If Energy Input < Energy Output, the temperature will decrease until they are equal.

What happens to the energy going into the system?

The object reflects some of the energy.

The object absorbs some of the energy.

The energy absorbed by the object causes the particles within it to move faster. This corresponds to an increase in kinetic energy of these particles and an increase in the temperature of the object. (One form of energy is transformed into another type of energy.)

Synthesis

During this portion of the class, what was learned in the computer modeling activity can be related to the Law of Conservation of Energy, (See the reference at *http://en.wikipedia.org/wiki/Conservation_of_energy* for background on this law) the importance of the Inverse Square Law, and the use of computer models in studying the earth system.

Once the object's temperature is higher than its surroundings, it begins to release energy to those surroundings in the form of electromagnetic radiation (visible and non-visible light waves: for example, heat or infrared waves). The higher the temperature of the object, the higher will be the frequency of emitted radiation and the greater the amount of energy released.

The temperature is related to the energy input by:

$$T = \frac{1}{2}\sqrt[4]{\frac{(1-\alpha)\,E_{source}}{\pi\,\delta\,D^2}}$$

where:

α is albedo,

E_{source} is total energy outputted by the source,

δ is the Boltzmann constant (5.67×10^{-8} W/($m^2 deg^4$)), and

D is distance between the source and the object.

In any system, the total amount of energy entering the system must be taken into account. Energy cannot be created or destroyed. It can only be transported and transformed. This is the Law of Conservation of Energy. In terms of our systems:

Energy into a system = Energy **reflected** by the system
+ Energy **absorbed** by the system
+ Energy **emitted** by the system.

And since this must be true each second, these relationships can also be expressed in terms of Power:

Power into a system = Power **reflected** by the system
+ Power **absorbed** by the system
+ Power **emitted** by the system.

Activity C OPTIONAL

Approximating the Average Surface Temperature of the Earth

1 class period

After studying some of the relationships that play an important role in determining the temperature of a planet, it is a good time to introduce the concept of average surface temperature. This activity can either be conducted in the computer lab using the Internet or by using the Reference: Global Temperature Data.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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.

Materials

Computer with access to the Internet. If you do not have Internet access, use the Reference: Global Temperature Data provided on page 56 in the Student Activities.

Engagement

What is the average temperature of the entire earth? This value, 15ºC, was discussed in Topic 1. A range of answers may be given. These may include the current temperature outside, room temperature, etc. After listing these temperatures on the board, pose the question: How do we determine which value is correct? After some discussion, the students will realize that at any given instant there are a variety of temperatures existing over the earth's surface.

Refer to the map, figure 1.1, in Topic 1 entitled, Global Measured Temperature Extremes. Identify a range of temperature extremes, as well as more comfortable or typical temperatures. The class is presented with a challenge to report a single temperature value that represents the temperature of the earth. What value should be reported? A decision to calculate the average temperature should be made.

Procedure

In the Computer Lab

Groups of two to three students are directed to the USA Today web site to obtain global temperature data: http://www.usatoday.com/weather/forecast/wglobe.htm. A minimum of 20 temperatures should be recorded on the Data Sheet, representing a variety of locales around the world. Individual groups average data values and report them to the class so that a class average can be computed. How close did the class get to Earth's average surface temperature of 15°C?

Note: The actual value for the average temperature of the earth can be obtained by several different ways. For example:

1. from infrared temperature measurements of the bottom 15,000 feet of the earth's atmosphere, taken by NASA satellites, or
2. averages of readings from thermometers at the surface.

In the Class

Groups of two to three students are given the Reference: Global Temperature Data. A minimum of 20 temperatures should be recorded on the Data Sheet, representing a variety of locales around the world. Individual groups calculate average data values and report them to the class so that a class average can be computed.

Consensus

The Investigation Questions are completed prior to conducting a class discussion concerning the following two questions: How close did the class get to Earth's average surface temperature of 15°C? How many data points do we need to derive a "good" average temperature?

Synthesis

Researchers are constantly in a position where they have to determine how much data is needed to study a problem and derive credible results. In calculating an average surface temperature for Earth using several data points around the globe, students can gain an appreciation for scientific decision-making, and the type and number of measurements that need to be taken.

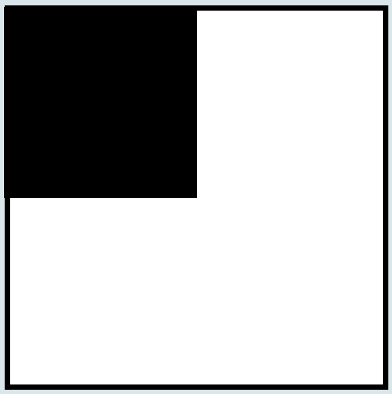
Evaluating Student Work

Topic 2. Modeling Hot and Cold Planets

Activity A – Investigation Questions

1. 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)



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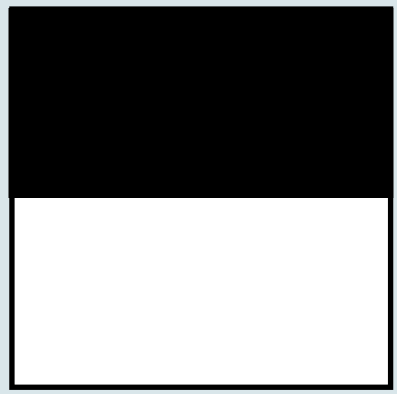
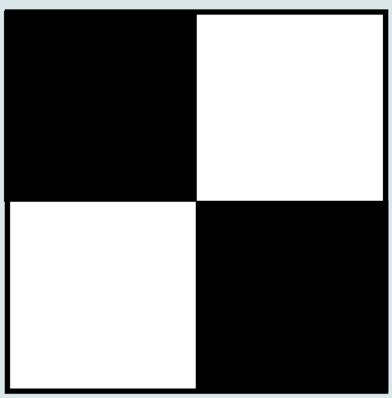
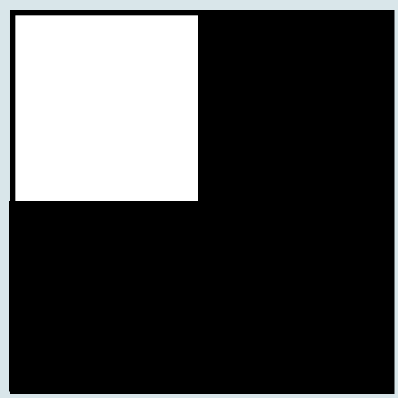


c)



d)



2. The temperature in New York City is projected to rise in the next few decades. Suggest ways to make the city a 'cooler' place to live.

3. 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

4. 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

5. You are an architect who has been asked to design a new library for a small town on the north shore of Hudson Bay in Canada. Based upon the ideas you have developed in these activities, what features might you consider including in your design so as to make the library comfortable for its patrons with the least expense?

6. 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.

Answer Guide – Questions 1, 3, 4, and 6

1. d.

3. b.

4. d.

6. The student should realize that solar radiation would be a primary source of heating, mention that light-colored materials were used for the body of the spacecraft in order to prevent overheating from solar radiation, and explain the relation between a body's color, its reflectivity, and its temperature. More complete answers that deal with thermal isolation of the spacecraft from the cold outside temperatures should receive extra credit.

With sufficient research, students should also discover that it is common practice to rotate spacecraft while they are in space so that no particular part of the spacecraft is continuously exposed to sunlight. They may also note that in the future, as spaceships are sent further out into the solar system, these issues will be less important with the increasing distance from the sun.

Activity B – Investigation Questions

1. A Bunsen burner is used to gently heat a beaker of water initially at room temperature. After several minutes, the temperature of the water is observed to stop increasing and remains constant. This final temperature is well below the boiling point of the water.

   a) What conclusions can you make about the energy inputs and outputs of the beaker under these conditions? Explain your reasoning.

   b) What would you expect to happen if the strength of the flame of the Bunsen burner is increased slightly? How do the energy inputs and outputs of the beaker/water system differ from your answer in question (a)? Explain your reasoning.

   c) What will happen to the beaker/water system if the flame of the Bunsen burner is turned off? Explain your reasoning.

2. A caffeine dependent inventor has developed what she considers to be the perfect thermos. Before leaving for work she fills her new thermos with coffee and observes the temperature of the coffee to be 50ºC. Several hours later she opens the thermos to take her first drink and observes the temperature of the coffee to be 49.6ºC.

   a) Is the thermos perfect? Justify your answer.

   b) Is the coffee/thermos system in equilibrium? Again, justify your answer.

   c) What are you able to conclude about the energy inputs and outputs of the coffee/thermos system?

Answer Guide

The answers to these questions should reflect the knowledge gained by the physical model experiment and the computer simulation of that model. If a system is in thermal equilibrium, its temperature is constant, and the total energy entering the system must equal the total energy leaving the system. If more energy enters the system, the temperature of the system will increase until the energy leaving the system again equals the energy entering the system.

Question 1

a) Since the temperature is constant, the system is in equilibrium. The energy inputs (heat from surroundings, heat from Bunsen burner, visible light) must equal the energy leaving the system (heat lost to the surroundings).

b) The input energy has increased, so the temperature will increase until the output energy is equal to the new input energy. A new, higher equilibrium temperature will be achieved.

c) When the Bunsen burner is turned off, the input energy will decrease. The temperature of the system will decrease until the output energy once again equals the new input energy. A new, lower equilibrium temperature equal to the temperature of the surrounding environment will be achieved.

Question 2

a) To be a perfect thermos, there should be no change in the temperature of the contents. No heat/energy should be lost or gained by the contents. Since the temperature of the thermos' contents has decreased, some energy has been lost by the system. The thermos is not perfect.

b) Answers may vary here – what is important is how the students justify their answers. Over a short time period (several minutes, for example), the temperature of the contents will not change measurably, so to the short term observer, the system will appear to be in equilibrium. Over the long term, however, it can be assumed that the previously observed heat loss will continue until the contents of the thermos are at room temperature. The long term, decreasing temperature indicates that the system is not in equilibrium.

c) The short term observer would conclude that input energy = output energy = 0 (due to insulation of the thermos). The long-term observer would conclude that output energy > input energy.

Activity C – Investigation Questions

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. Collect your temperatures in a spreadsheet. Use the spreadsheet to find 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?

Answer Guide

Questions 1 through 3

The students should understand that in order to get a good average value they should sample the different temperature regimes (high/low latitudes, land/ocean) in proportion to their coverage of the planet. The more samples they use in each regime the closer their average will be to the correct value.

Question 1

a) The average should vary, but as the number of samples increases, the value of the average should start to approach a specific value.

b) The temperatures over land should yield a higher average in the summer and a lower average in the winter.

Question 4

15ºC or 59ºF is a round value for the average surface temperature of Earth. The students should discuss which realization of their averages was closer to the actual value and why. Their explanations should refer to their answers to questions 1 through 3.

Essay: Real World Problem – Preparing for Mars Living in an Arctic Outpost

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?

Assignment: Write a 300 word essay that responds to the questions in this topic's Real World Problem. 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.

Minimum Expectations for this Essay

✓ Student should make a statement agreeing or disagreeing with the selection of Haughton Crater as an experimental Mars habitat on Earth.

✓ Student should provide a brief defense (three reasons based on geological or atmospheric criteria) of their agreement or disagreement with this choice.

✓ Students should list at least four conditions that would need to be considered in order to make the site habitable for humans over the long term.

✓ For each of the conditions described above, students should describe the adaptation that would be required and what kind of materials would be required.

✓ For each adaptation above, the student should use the reasoning developed in Topic 2 to explain how this adaptation will help to make the site habitable.

✓ Students should give at least two other areas that would need to be considered for a long-term Mars habitation. (Example: The need for several members to have medical knowledge. A number of doctors have had to be "rescued" from Antarctic research stations because their conditions were not treatable at the facilities, or, there was no other doctor available to help them.)

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

Topic 3

Using Mathematical Models to Investigate Planetary Habitability

Overview

Students use mathematical computer models to describe the physical models constructed in Topic 2. These models will be derived from laboratory experiments (Activity A), from real world data (Activity B), and to varying degrees of complexity (Activity C). As powerful tools for science research, these models can help determine the climate system's dependence on variables that cannot easily be simulated in a laboratory.

Activity A: A simple mathematical model is derived by fitting a curve to observed data. Students will determine the mathematical relationship describing:
i) how the intensity of energy changes as a function of distance from a light source, and
ii) how the temperature changes as a function of distance from a light source.

Activity B: A simple mathematical model of the solar system is developed. Relationships derived in Activity A are used to determine the intensity of energy from the sun reaching the planets, and the temperatures of different planets.

Activity C: Adding complexity to models. Students will notice problems with results obtained in Activity B. Planetary albedo is introduced. A more complex model called *Global Equilibrium Energy Balance Interactive Tinker Toy* or GEEBITT will be employed to study the effect of adding this variable. An average albedo of earth and other planets will be determined with NASA data.

At the end of these activities, the students discuss what factors may influence a planet's temperature, other than distance and albedo. This leads to Topic 4, where the effect of a planet's atmosphere and the Greenhouse factor are considered.

Science Content

The relationship between data and mathematical models
Most scientists studying global warming use mathematical models to simulate the earth's atmosphere, oceans, and land surface processes. These mathematical models have advantages and disadvantages.

Activity A: Students use a physical model of a sun–planet system to obtain data describing relationships between (1) distance from the sun and intensity of light reaching the planet, and (2) between the planet's surface temperature and sun distance. Can observed data be described using a simplified mathematical relationship? How well can we describe physical interactions or conditions with mathematical relationships?

Activity B: To simulate the planet's temperatures we need to use a computer. Students use a simple spreadsheet program to develop their own computer model using the observed data collected from their physical model to set the initial conditions. While mathematical models take us to places where we cannot physically go, what are disadvantages of such models?

Earth's surface features and atmospheric properties influence planetary albedo
NASA satellite data is used to determine the average albedo of the earth. A simplified version of the GEEBITT is introduced to study factors that influence planetary albedo on Earth, Venus, Mars and Mercury. Characteristics of the actual and modeled planets are compared to assess the effectiveness of the model. This leads to a discussion of why albedo differs among the planets and which factors are most important in determining a planet's temperature and habitability.

Activity C: How does the earth's color affect its temperature? What about other planets? Is reflectivity or albedo important in determining a planet's temperature? How sensitive is the earth's temperature to changes in albedo?

Science Skills

Measurement and experimental design
Students design two experiments with physical models to determine the mathematical relationships between (1) distance from an energy source and intensity of energy at that distance, and (2) distance from an energy source and temperature of the object. Experiments are performed using solar cells and volt meters to collect data and determine these relationships.

Data analysis and trends in data
By graphing results of the two physical model experiments, students are able to relate the variables under consideration. A spreadsheet is used to replot the data, using some of the built-in analysis utilities, e.g., best-fit line.

Mathematical models, comparison of actual and model data, model development
The mathematical relationships discovered by the students are used to produce simple mathematical models in a spreadsheet program. Results are compared to actual data as part of the model development process. A second comparison with actual data reveals this as an iterative process. The final model is used to evaluate the relative effectiveness of various factors in maintaining planetary temperature and habitability.

Considering a Real World Problem

Deforestation and Urban Heat Islands

Earth's surface features are continually changing. In our planet's ancient past, natural events caused the earth's global mean temperature to cool to such an extreme that ice and snow covered much of its surface, producing an Ice Age. But today there is another variable to consider as a forcing on the planetary landscape and habitability – human civilization.

In Topic 3, students are introduced to the concept of planetary albedo. They determine mathematical relationships between several of the factors they have been studying that influence a planet's average temperature. They will be able to apply these understandings to consider two ways humans are altering Earth's surface features: 1) clearing land for agriculture and producing deforestation and 2) building cities, suburbs, and road systems that contribute to the Urban Heat Island Effect.

Students will be asked to consider how these two human impacts on Earth's land surface changes result in changes to surface and atmospheric albedo, as well as influence planetary temperature. By asking them to quantify and justify their responses based on their modeling activities in Topic 3, they can explain the scientific understandings they developed and apply them to current environmental problems.

Activity A

Finding a Mathematical Description of a Physical Relationship

4 class periods

In this first activity, students will derive a mathematical description (an equation) of the relationship between distance and the amount of energy received. Using this equation, they will produce a simple mathematical model that can determine the incident energy and the resulting surface temperature of a planet in the solar system. Emphasis should be placed on the process of taking observations, finding relationships, and modeling those relationships to describe situations that cannot be precisely duplicated in the laboratory.

An experiment design, with solar cells connected to volt meters, provides the data for students to measure the intensity of the light at certain distances perpendicular to a light source. Students record observations and plot them by hand on a graph. The relationships found in their graphs are described both in their own words and mathematically.

How do we obtain an "exact" mathematical description? A spreadsheet program is introduced to reproduce the hand plotted graph using a computer. Have students discuss the advantages of using a computer spreadsheet. The power of the spreadsheet is revealed when the students find the best-fit (linear and non-linear) for this data. The Inverse Square Law can be derived by generating the equation of the curve that best fits the data using the spreadsheet tools. By predicting the intensity at a point not yet tested, and then comparing that value to an actual measurement, students verify the validity of the equation.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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.

Materials

Light sources (150 watt light bulbs)
Support for light source
Solar cell/sunphotometers (Solar cells can be purchased from Radio Shack)
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

Engagement

Class Period 1

Review the results from the hot and cold planet experiment conducted in Topic 2 by summarizing the observed relationships. Students may respond by saying, "the brighter the surface, the lower the temperature," or "the farther away the planet, the lower the temperature." Discuss how descriptions can be made more exact and detailed. To facilitate the discussion:

"Well, you say that if the distance gets larger, the temperature gets lower. Can you tell me how much lower the temperature will get if you double the distance? What would you need to know to answer this question?"

The need for more data should become clear, specifically the distance and the temperature or brightness at various distances to derive a more exact relationship.

Procedure

An experiment design challenge is presented to study the relationships between distance, temperature, and intensity of light at different distances. Distribute handouts for students to complete: (1) Team Members, (2) Experimental Design Proposal, and (3) Methodology for a Controlled Experiment. Review the function of a solar cell and volt meter as materials to be used in the experiment. Divide the class into teams of five. Each team must have a leader and two sub-teams, one to measure the distance–temperature relationship, another to measure the distance–intensity relationship.

Class Period 2

Distribute the Data Sheets: Physical Model Experiments, for students to record the data collected from the physical model. The instructor can circulate around the room and provide help or suggestions as needed. Students work in their laboratory groups to complete the handout Experimental Results: Physical Model Experiments. Part of this handout involves the use of a hand drawn graph to determine mathematical relationships from the experimental data.

Consensus

Class Period 3

Following some discussion of the physical model results, introduce the spreadsheet computer program. Distribute the handout Experimental Results: Deriving Quantitative Relationships with a Spreadsheet. This serves as a guide for plotting results with a spreadsheet program. Students compare the results graphed by hand and the spreadsheet. Collectively, all the investigation groups decide the best way to represent the relationships from their experiments.

Synthesis

Class Period 4

The activity concludes with a discussion of results produced in the two experiments. What is the relationship between distance and temperature or distance and intensity that the students could not say before the experiment and the plotting exercise? How reliable are the results? The Investigation Questions should be completed.

Activity B

Making a Simple Mathematical Model

3 class periods

Using their observed results for the relationship between distance and the energy reaching an object, students will make a simple mathematical model with a computer spreadsheet program. These models will be developed with the capability to change the luminosity and distance of their light source and to calculate the energy reaching the object, and its black body temperature. Experiments will be designed to obtain the theoretical black body temperatures of Earth, Venus and Mars. By comparing model results to the actual temperature values, students can continue to discuss planetary differences, the role of models in science and possible improvements to their spreadsheet model.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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.

Materials

Computer loaded with Microsoft Excel software, and the equations derived by students in Activity A

Engagement

Class Period 1

Students review the results from the Radiation Balance Model computer simulation. All the scenarios achieved equilibrium temperature, but the farther away the object, the lower the equilibrium temperature as less energy reaches the object. Students should be able to describe the Inverse Square Law qualitatively. Ask: How did the simulation achieve these results? How would they go about making a simulation that could give results similar to that of the Radiation Balance Model simulation?

Procedure

Review the concept that mathematical models use equations to determine their results. These equations describe relationships observed in nature, such as the Inverse Square Law. The more complicated the relationship to be simulated, the more sophisticated the model must be. Students go through the introductory activity of how to use a spreadsheet.

Class Period 2

Students use the mathematical equations describing the effect of distance from a source upon (1) the intensity of light reaching an object at that distance, and (2) the temperature of the object. They will build a simple mathematical model that determines the black body surface temperature of a planet given its distance from the sun. The luminosity of the sun and the solar constant at the surface of the sun are provided. Students are then assigned the task of building their spreadsheet model while referring to the instructions provided in the handout: Learning Excel: Applying Features of a Spreadsheet Program to Create a Simple Planetary Model.

Class Period 3

Students complete the spreadsheet models and determine the black body temperatures of Earth, Venus and Mars. Results are compared to the observed values and the role of models in science investigations is discussed. At this point, the instructor may introduce the Inverse Square Law and the Stefan-Boltzmann Law as the "actual" relationships and have students critique their own equations.

Consensus

A comparison of the spreadsheet models is conducted. Students discuss how predictions made for the solar constants and surface temperatures for Venus, Earth, Mars and Mercury compare to the actual values. By determining the percent error of their predictions, they can discuss which models did a better job predicting the true values, and why. What made some models better than others? What were the strengths and weaknesses? What are the advantages and disadvantages of using spreadsheets to model planets?

Synthesis

After completing the Investigation Questions, the class reconvenes to discuss their responses. In discussing model improvements, it should be emphasized that a model is never finished. Its continued development is an effort to improve our understanding of the processes being simulated.

Extra Credit: Provide students with the Inverse Square Law and the Stefan-Boltzmann Law and ask them to include these relationships in their spreadsheet models. They should modify their spreadsheets and then compare the new model to older versions.

Activity C

The Role of Actual Data in Mathematical Models

1 class period

One of the improvements that students should suggest making to their spreadsheet models is to include the albedo of the planet. Students will use an advanced spreadsheet model called *Global Equilibrium Energy Balance Interactive Tinker Toy* or GEEBITT, that includes an albedo factor as well as some other features, to investigate the effect of the planet's albedo. In order to properly utilize this model, students will be first asked to determine the earth's albedo by examining NASA data. They will then use a spreadsheet called *Albedo Calculator* to determine the value of the albedo to use in GEEBITT. The resulting model values for the gray body surface temperatures of Earth, Venus and Mars are again compared to the actual values of these temperatures. (*Note: A "Black Body" is a perfect emitter and absorber of energy. A "White Body" is an object that reflects all of the energy it receives and therefore absorbs none of that energy. Both Black and White bodies are ideal objects and do not actually exist, though some materials come close to these behaviors. Objects in the universe are really "Gray Bodies", both reflecting and absorbing some of the energy they receive.*) The students are then asked to propose explanations for observed discrepancies and suggestions on how to improve the model.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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 their spreadsheet models.

Materials

Computers loaded with Microsoft Excel software
Plots of the earth's albedo as seen by satellites
Spreadsheets Albedo Calculator and GEEBITT. These can be downloaded from the web site: http://icp.giss.nasa.gov/education

A user's guide to GEEBITT can be found in the Appendix of the Student Activities.

Engagement

The instructor should direct students to their suggestions from the previous class period on possible improvements of their spreadsheet models. One of the suggestions will probably have been the inclusion of albedo. To do this, we need to modify the model and determine a value to use for the albedo of the planet. At this point the instructor can review the concept of albedo and show the class an albedo map of the earth obtained from satellite observations and have the students try to interpret the map. Students will see that there are a variety of albedos, and can be asked which value could be used to represent the albedo of the entire planet. Someone may suggest using the average value, and the teacher can ask how that would be done. After students suggest a possible procedure, the teacher can explain the albedo calculator map activity.

Procedure

Students are divided into groups of five. Each group is assigned a portion of the earth and instructed to determine the percentage of their portion that is ocean, vegetation, desert, or ice. The percentages are entered into the Albedo Calculator spreadsheet to determine the average albedo of that portion. The average albedos of each portion are then collectively averaged in order to obtain the albedo of the earth.

After the students have determined the average albedo, the teacher can ask if they are done, or if there is something else that needs to be included. If they are unable to answer, the teacher can show them photographs of Earth taken from space. At this point some students should point out that we have not included the clouds and the effect they have on albedo. The students are then given a plot of the average cloud cover in their region, and asked to determine the effect of the clouds on albedo and incorporate this into the Albedo Calculator. A value of the average albedo of the earth including cloud effects is finally derived.

Students then use this value as well as the albedos of Mars and Venus in mini-GEEBITT, Version A, which includes albedo. Students obtain their theoretical gray body temperatures of these three planets.

What are the gray body surface temperatures of Venus, Earth, and Mars?

Students compare their model results with the actual surface temperature of the three planets. The discrepancies are now found to be even greater (particularly with Venus' cloud cover), and the students are asked to explain the inadequacies of this model.

Consensus

Have students suggest other modifications that may be necessary to improve the model's simulation of real planets.

Synthesis

Once again, students are asked why the temperatures of the simulated planets still do not agree with observed values. A concluding discussion follows and they should complete the Investigation Questions as homework.

Evaluating Student Work

Topic 3. Using Mathematical Models to Investigate Planetary Habitability

Activity A – Investigation Questions

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

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

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

4. Now that you have mathematical relationships between distance, intensity, and temperature, how can you use them to study planetary conditions in the solar system?.

5. Engineers are given the task to light Yankee Stadium for night games. How can they go about deciding the intensity and distance of the lights from the field?

6. 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?

Answer Guide – Questions 1 through 6

Students are expected to comment on the usefulness of physical and mathematical models and the uncertainties of experimental data. It is important to understand that once derived, mathematical relations have the advantage that they can be applied to all kinds of different situations.

Activity B – Investigation Questions

1. Does your model produce temperature differences between the planets that agree with your expectations? Explain.

2. Do you think that modeling planets as black bodies provides an accurate representation of the planets' temperatures? If not, how can you improve the model to derive more accurate results?

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

Answer Guide – Questions 1 through 3

The students are expected to understand that the black body temperature is only an assumption to illustrate the effect of the distance from the light source on the temperature of the planet, and is the first part in a process to calculate the correct temperature. They should also understand that mathematical models are only as good as the input that goes into the calculation and the accuracy of the equations that are used.

Activity C – Investigation Questions

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 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: World Albedo Maps for January and July. 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? Give an explanation as to 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 temperatures with albedo compare to the actual surface temperatures? What other factors may need to be modeled in GEEBITT in order to calculate a better surface temperature estimate?

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

Answer Guide

Questions 1 through 5

The students should understand that higher albedo means cooler temperature and that elements like ice and snow on the earth's surface increase the planetary albedo. Also human intervention with acts like deforestation can have an effect on the planet's albedo.

Questions 6 and 7

Students are expected to understand that including the albedo in the calculation of the surface temperature of a planet adds one more degree of complication to the calculation but does not get us any closer to the right answer. Based on their experience with the physical models they should hypothesize that the missing ingredient that will give the right surface temperatures has something to do with the presence of an atmosphere around the planets.

Essay: Real World Problem – Deforestation and Urban Heat Islands

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

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. 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?

Assignment: Write a 300 word scientific essay that addresses temperature changes as a result of variations in albedo on the Earth's surface and atmosphere. How will replacement of forests with agriculture 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 using evidence from your experiments with the Albedo Calculator and GEEBITT. Include examples found on the Internet of areas where humans may be changing albedo and temperature. Refer to the References: Regional Effects of Human Development – Deforestation, and Regional Effects of Human Development – Urban Heat Islands.

Minimum Expectations for this Essay

- ✓ Students should explain what they think the effect of removing forests will have on the albedo of those areas.
- ✓ Students should explain what they expect large-scale deforestation of the Amazon will have on local and global temperatures.
- ✓ Students should describe at least two other factors that would affect temperatures locally and globally.
- ✓ Students should give at least three reasons why temperatures of cities increase as the cities increase in size.
- ✓ Students should justify these reasons with evidence from their experiments and other named sources.

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?

Topic 4

How do Atmospheres Affect Planetary Temperatures?

Overview

Topic 4 is a synthesis of the skills and knowledge obtained in the first three topics. Students will utilize these abilities to explain the Greenhouse Effect and its influence upon the surface temperature of a planet.

Activity A: The students brainstorm as to why the observed surface temperature of Earth is so different from that observed by their gray body model. Then they do a literature search to obtain information about the atmospheres of Earth, Venus and Mars. They speculate as to which characteristics of the atmospheres may be responsible for the difference between observed and theoretical surface temperatures. Students then use separate samples of carbon dioxide and air to observe interactions of the compound and the mixture with incident light or heat. The activity ends with a definition of the Greenhouse Effect.

Activity B: Students review the characteristics of Greenhouse gases and their interaction with energy by performing a classroom simulation. In this simulation they use play money to represent energy and follow certain protocols as to the interaction of atmospheric gases with electromagnetic energy in order to reinforce their understanding of the roles of various gases.

Activity C: Students use information obtained from their literature search in Activity A to estimate Greenhouse factors for the atmospheres of the three planets, and then use the models to check and refine these values. They use a modified version of the mini-GEEBITT mathematical model to investigate the Greenhouse Effect. The students attempt to produce surface temperatures for Venus, Earth and Mars that are closer to the actual surface temperatures of these planets than they have achieved with earlier models.

Activity D: The students are assigned the task of determining a combination of the four factors - luminosity of the source, distance from the source, albedo of the planet, and the Greenhouse Effect - that would allow them to "terra-form" Venus and Mars. They use mini-GEEBITT to vary each of the four factors for Venus and Mars to find these combinations. They must then explain how these factors could be changed by developing a hypothetical, but logical scenario based upon their final combination.

The topic ends with a summary by the students and an essay addressing the Real World Problem: Culprits of Climate Warming and Cooling.

Science Content

Experiments and observations in the earlier topics have shown students that in general, the presence of an atmosphere around a planet has a warming effect upon the surface of the planet. Earth, Venus and Mars all have average surface temperatures higher than a black body would, if placed at their distances from the sun. For more information about black bodies please visit the site: http://en.wikipedia.org/wiki/Black_body?

Activity A: Students perform a literature search to investigate the characteristics of the atmospheres of Earth, Venus and Mars and hypothesize as to which characteristics may be responsible for the difference between the observed and theoretical surface temperatures of these planets. They perform an experiment to observe the interaction of carbon dioxide gas and light energy and relate this to the observed differences in temperatures.

Activity B: The students perform a series of simulations to review how Greenhouse gases produce this warming effect. Emphasis is placed upon the relatively low concentrations of these gases in the Earth's atmosphere and the magnitude of their effect upon the surface temperature. Students review how Greenhouse gases emit infrared radiation back to a planet's surface, thus increasing its temperature.

Activity C: The students use the results of the experiment in Activity A and their literature search to predict magnitudes of the Greenhouse factors for Earth, Venus and Mars. They then use a modified version of the mini-GEEBITT model to check these predictions and obtain Greenhouse factors for the three planets.

Activity D: The students apply the knowledge they have acquired throughout the module to develop hypothetical, but logical scenarios for terra-forming Venus and Mars. They also evaluate the practicality of their proposed scenario by producing "habitable" temperatures for Venus and Mars with the mini-GEEBITT model.

Science Skills

Measurement and experimental design

Students carry out experiments with a mathematical model to determine the relative effectiveness of the major factors that determine the surface temperature of a planet. They also perform an experiment to investigate the feasibility of Venus or Mars being able to maintain a temperature suitable for the habitability by humans. The significance of these model results is related to the real world.

Data analysis

Students record the temperatures over time of samples of air and carbon dioxide exposed to a light source. They then produce data sets from a series of classroom simulations in order to determine the energy budgets of three sun-planet systems. The results of these simulations are used to describe the effect of the Greenhouse gases on a planet's temperature. Students use a mathematical model to evaluate predicted values for Greenhouse factors for Earth, Venus and Mars that would make their temperatures more comfortable to human beings. These theoretical results are compared to the actual changes that would have to be made to the planets to evaluate feasibility of such changes.

Considering a Real World Problem

Culprits of Climate Warming and Cooling

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.

What are significant factors that influence a planet's climate and in particular Earth? What are important relationships among these factors? Students will use the information presented in the Real World Problem and the knowledge developed in Topics 1-4 to explain their response in an objective, scientific, clear and useful way for the public and policymakers. The culminating essay gives students an opportunity to synthesize their understandings in *What Determines a Planet's Climate?* It also allows them to apply this knowledge to important questions facing climate researchers and the public. How might trends in carbon dioxide, temperature and population over the past century relate to the greenhouse effect and Earth's climate? What if there is a strengthening of the greenhouse effect caused by human activities? How will other factors that affect Earth's climate respond? For example, how might 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?

Activity A

How do Atmospheres Interact with Solar Energy?

5 class periods

Topic 4 builds upon the understandings that students have acquired in the previous three topics. They should now be aware of how three factors (luminosity of the source of energy, distance from that source, and planetary albedo) can influence average temperature of the surface of a planet. They should also be aware from their comparisons of model and direct observations that these factors alone are not sufficient to determine a planet's average surface temperature. They have preliminary evidence that the atmosphere of a planet plays a role in maintaining the surface temperature of the planet. Planets with atmospheres have higher temperatures than their gray body models predict.

Activity A begins with a self-review of the students' current state of knowledge of the surface temperatures of the terrestrial planets of our solar system, and how the observed values differ from those predicted by a gray body model. The discrepancy in temperature is different for different planets. If the assumption is that the atmospheres of these planets are responsible for the discrepancies, then there must be differences among them that account for the range of deviations. Students then perform a literature search using a library and/or the Internet to determine as much as they can about the atmospheres of these planets. They then hypothesize as to what characteristics of the atmosphere may be responsible for this warming effect.

One assumption that will result from this exploration is that the composition of the atmosphere may be the difference that counts. Students perform a physical experiment to test the reaction of samples of carbon dioxide and air to exposure to light. The entire class then comes to a consensus as to which characteristics of an atmosphere are most likely responsible for this warming effect. Students identify the accepted name for this effect, the Greenhouse Effect, and are asked to provide a preliminary definition of their own making.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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.

Materials

Images of Mercury, Venus, Earth and Mars, access to a library with planetary science references or, preferably, access to the Internet (possibly as a homework assignment).

For each laboratory group:
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 tubes 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

Engagement

Class Period 1

The teacher can begin this activity by having the students summarize what they know about the factors that affect the surface temperature of a planet. They should be able to refer to their results from the previous three topics. They should bring out the fact that some of the physical models they constructed had plastic coverings and that this produced higher temperatures in these models than in those without coverings. What effect do atmospheres have on planetary surface temperatures? Have students fill out the table on the first page of the Activity A handout, and let them discuss the ramifications of the results among themselves. The table is provided here with the values already included:

Planet	"Gray" Body Temperature		Actual Surface Temperature		Percent Difference	Is An Atmosphere
	K	ºC	K	ºC	(from K)	Present?
Mercury	435	162	440	167	1.2 %	yes, very thin
Venus	229	–44	737	464	68.9 %	yes, very thick
Earth	254	–19	288	15	11.8 %	yes, thick
Mars	210	–63	210	–63	0 %	yes, thin

Table 4.1.

Showing pictures of these planets at this time may help the students come to a consensus. The students should note that planets with the thickest atmospheres seem to have the greatest warming effect. If students have not mentioned it, the teacher can now introduce the term "Greenhouse Effect" as the scientific name for this atmospheric warming of a planet's surface. At this point, no further explanation of the Greenhouse Effect should be attempted. The teacher should have the students hypothesize as to what exactly about the atmosphere is able to produce this warming effect. Students should be able to come up with several possibilities, including the thickness of the atmosphere (or atmospheric pressure), the composition of the atmosphere (component gases, specific gases, or the relative amounts of these gases.) Suggestions may include that a thicker atmosphere traps more heat like the plastic covering on the physical model, or that certain gases do the trapping, and so on.

Procedure

After the students have a variety of hypotheses as to how an atmosphere could produce the observed warming effect, they need to test their hypotheses. Since they are unable to visit each of these planets, they will be required to do a literature search to determine what is currently known about the atmospheres of these planets, and see if any of their hypotheses can be disproved by this information. The students are then asked (either as homework or as class work if the resources are available) to complete table 2 with as much information about the atmospheres of these planets. They should also be asked to consider the various hypotheses that have been proposed and decide if any of them can be eliminated, or if any of them are better explained by the observed values. An example of how a student might complete table 2 is included here for the teacher's use. A more complete table of atmospheric composition is provided on page 73. (*Note 1 bar is approximately 1 atmosphere of pressure, 1 mb = 1 millibar*)

Planet	Mercury	Venus	Earth	Mars
Atmospheric Pressure (bar)	10^{-15}	92	1.014	0.006
Clouds?	none	100%	Yes, but variable amounts	Yes, but very thin
Winds (m/s)	none	0.3 to 1	0 to 100	2 to 30
Oxygen (%)	42	0	20.946	0.13
Nitrogen (%)	trace	3.5	78.084	2.7
Carbon Dioxide (%)	trace	96.5	0.035	95.32
Water (%)	trace	0.002	varies, ≈1	0.021
Other gases (%)	Sodium 29 Hydrogen 22 Helium 6 Potassium 0.5	Sulfur Dioxide 0.015 Argon 0.007 Carbon Monoxide 0.0017	Argon 0.934 Neon 0.0018 Helium 0.00054 Methane 0.00017	Argon 1.6 Carbon Monoxide 0.08 Nitrogen Oxide 0.01

Table 4.2. Values were obtained from NASA's National Space Science Data Center (http://nssdc.gsfc.nasa.gov/).

Class Period 2

At the end of the discussion of the significance of their findings, some students may argue that the amount of atmosphere (atmospheric pressure) is the most important factor in explaining how the Greenhouse Effect occurs. But then how do they explain the different effects on Mercury and Mars? Some students may argue that the composition is more important, noting that Venus has the least mixed atmosphere, and is mostly composed of carbon dioxide. Have students discuss how they might test these hypotheses with physical experiments. Testing effect of the atmospheric pressure would be difficult to do in the school laboratory, but testing the effect of certain gases is not. Propose the experiment that follows in the Student Activities, comparing the heating properties of a sample of air (Earth) with a sample of pure carbon dioxide (approximately Venus).

Class Period 3

The teacher should separate the students into groups of three or four, and then demonstrate the technique the students should use to produce a sample of pure carbon dioxide using Alka-Seltzer tablets and a water trough. Have the groups complete the handouts for the Experimental Design Proposal, the Methodology for a Controlled Experiment, and then perform the experiment as they have planned it. Be sure the lamps the students use produce a lot of infrared (heat) radiation. Normal incandescent light bulbs will work, and should be placed within 15 cm of the gas filled beakers for best results. (*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.*)

Class Period 4

Each student should graph his or her group's results. They should observe that the container of pure carbon dioxide reaches a higher temperature than the air sample at a faster rate. They should then answer the questions at the end of the activity and the class should come together for a final group discussion.

Consensus

Class Period 5

In their discussion, the students should note that we have not disproved that atmospheric pressure may be a contributing factor to the Greenhouse Effect since they did not perform an experiment to test that hypothesis. They have observed that the composition of the atmosphere *does* play a role in its warming ability. Carbon dioxide is just one example of a gas that can trap heat in the atmosphere. Other gases that have been tested and found to have a similar effect are water vapor and methane. Collectively, these gases are called Greenhouse gases.

Synthesis

Have students compare the amounts of the Greenhouse gases in the various atmospheres. Mercury has only trace amounts of any Greenhouse gases, and a very thin atmosphere. Venus has almost 97% of its thick atmosphere composed of Greenhouse gases, while Earth has only about 1.04% of its atmosphere composed of these gases. Mars, with another thin atmosphere, has about 96% of its atmosphere made of Greenhouse gases. So, while the percent composition of the atmosphere is important, the amount of atmosphere does seem to play a role. Venus, with an atmospheric composition similar to that of Mars, has a much larger Greenhouse Effect. What still needs to be explained is exactly how these Greenhouse gases produce their warming. What is the mechanism behind the Greenhouse Effect?

Reference

Characteristics of Four Planetary Atmospheres

Gas	Composition (in % or parts per million (ppm))			
	Earth[1]	**Venus**	**Mars**	**Mercury**
Nitrogen (N_2)	78.08%	3.5%	2.7%	trace
Oxygen (O_2)	20.98%	–	0.13%	42%
Argon (Ar)	0.93%	70 ppm	1.6%	–
Carbon Dioxide (CO_2)	0.035%	96.5%	95.32%	trace
Neon (Ne)	0.0018%	7 ppm	2.5 ppm	trace
Methane (CH_4)	0.0017%	–	–	–
Krypton (Kr)	0.0011%	–	0.3 ppm	trace
Helium (He)	0.0005%	12 ppm	–	6%
Xenon (Xe)	0.00009%	–	0.08 ppm	trace
Hydrogen (H_2)	0.00005%	–	–	22%
Nitric Oxide (N_2O)	0.00005%	–	–	–
Sulfur Dioxide (SO_2)	–	150 ppm	–	–
Carbon Monoxide (CO)	–	17 ppm	0.08%	–
Water (H_2O)	0.1 to 4%	20 ppm	210 ppm	trace
Sodium (Na)	–	–	–	29%

	Other Atmospheric Properties			
Average pressure at the surface	1014 mb	92000 mb	6.1 mb	1×10^{-12} mb
Density at the surface	1.217 kg/m^3	65 kg/m^3	0.20 kg/m^3	NA
Scale height[2]	8.5 km	15.9 km	11.1 km	NA
Mean molecular weight	28.97 g/mole	43.45 g/mole	43.34 g/mole	NA
Surface wind speed[3]	0 to 100 m/s	0.3 to 1 m/s	2 to 30 m/s	NA

Table 4.3. Source: NASA's National Space Science Data Center

Notes:
1. Percentages for Earth's atmosphere are based on a dry atmosphere.
2. Scale height: height interval in which atmospheric pressure drops by a factor of p/e = 0.38 (37%)
3. Wind Speeds: near surface wind speeds in meters/second.

Activity B

How do Atmospheres Produce their Effect Upon Surface Temperatures?

4 class periods

After investigating the warming effect of several planets' atmospheres, the students were left with the question as to how the atmosphere actually produces this effect. They attempted to relate the actual characteristics of the planetary atmospheres to their warming ability, but no concrete conclusions could be made. Further investigation is necessary. Do 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? Do human activities influence any of these components?

In this activity, students explore the influence of atmospheric gases, in particular greenhouse gases, on planetary temperature. For the purposes of this activity, we isolate the process of how greenhouse gases are exchanged in our atmosphere and interact with energy. Therefore, it does not take into account the range of factors in the planet system that contribute to planetary temperature and energy balance such as surface features and clouds.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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 perspectives on 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.

Materials

Set of play money: $100, $50, $20, $10, $5 and $1 bills
A copy of the Energy Interaction Protocols for the simulations

Engagement

Class Period 1

The instructor can begin the activity by asking: What is the mechanism by which atmospheres affect the surface temperatures of their planets? The students concluded Activity A by proposing several hypotheses as to what properties of the atmosphere are responsible for the observed warming effect. Have them review those hypotheses and suggest possible mechanisms for those hypotheses. Eventually it should become clear to them that they need a better understanding of how the atmosphere and the planet interact with energy. The teacher can then explain the nature of the simulation that the students will carry out during this activity.

Procedure

Before beginning the simulations the instructor needs to ensure that the students have a basic understanding of the Law of Conservation of Energy and the relationship between temperature and energy. A review of Activity B, Topic 2 would be appropriate at this point. The instructor can remind the students of this activity by reviewing some of the questions from that topic. Why does a cold object warm up when placed in a warm room? What will its final temperature be? What must be true about the energy going into the object compared to the energy leaving the object? Why must this be true? Verify that students understand the difference between short-wavelength and long-wavelength electromagnetic radiation and their relationships to heat and energy. Why do objects feel warm? Why do objects feel cool?

Define a simple system consisting of the sun and a featureless planet. Elicit: what are the sources of energy in this system? What happens to this energy after it leaves the source? What happens to the energy when it hits the surface of the planet? What happens to the planet? Why does the planet eventually reach an equilibrium temperature? In the simulations that follow, students will record the energy budget for three different sun-planet-atmosphere systems and interpret the differences in these budgets, ending with an explanation of how greenhouse gases are able to warm a planet.

Class Periods 2 and 3

How do the various gases in the atmosphere interact with high and low frequency electromagnetic waves/energy? Three simulations act as a model for these interactions in the classroom. In the first simulation, one student will play the role of the sun while a second student will play that of the planet's surface. The students will use play money to represent incoming high frequency solar energy (100 dollar bills) and outgoing low frequency infrared energy (20, 10, 5 and 1 dollar bills). At different stages of the activity, other students will be added to represent molecules of oxygen and nitrogen in the atmosphere and then finally carbon dioxide and water vapor as examples of the greenhouse gases. All students will have to follow specific rules as they interact with the energy/play money. Students will observe all three simulations and record their observations on a handout, and answer specific questions about 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 planets'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 teacher.

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.

Emphasized to the students representing oxygen and nitrogen:

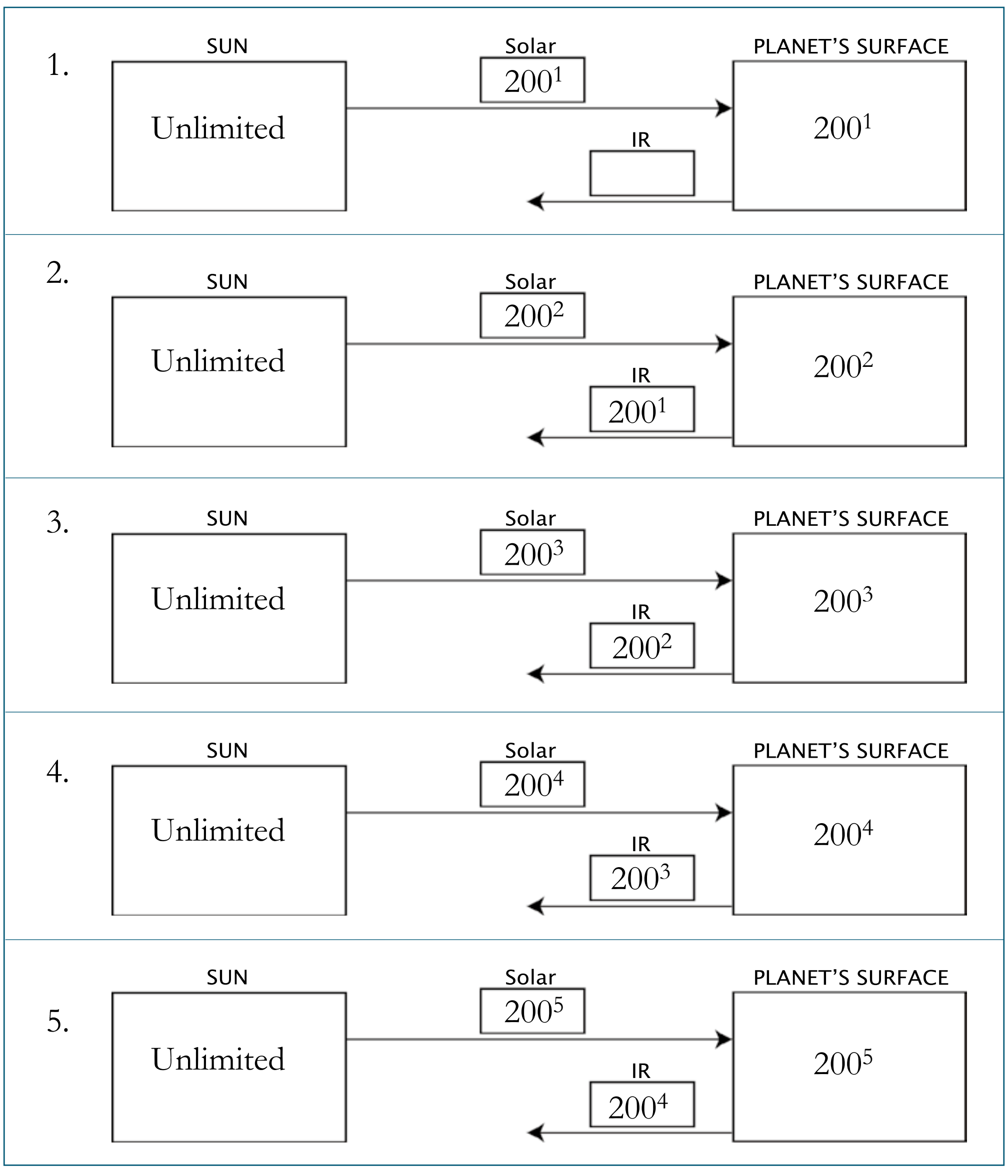
4. Do not interact with any type of energy. Simply watch the transactions as they occur.

Emphasized to the students representing carbon dioxide and water vapor:

5. Do not interact with any solar energy, simply watch it go by. Grab any infrared energy that comes your way and hold onto it for one turn, then pass half of it back to the planet's surface and the other half out into space.

Simulation 1: No Atmosphere

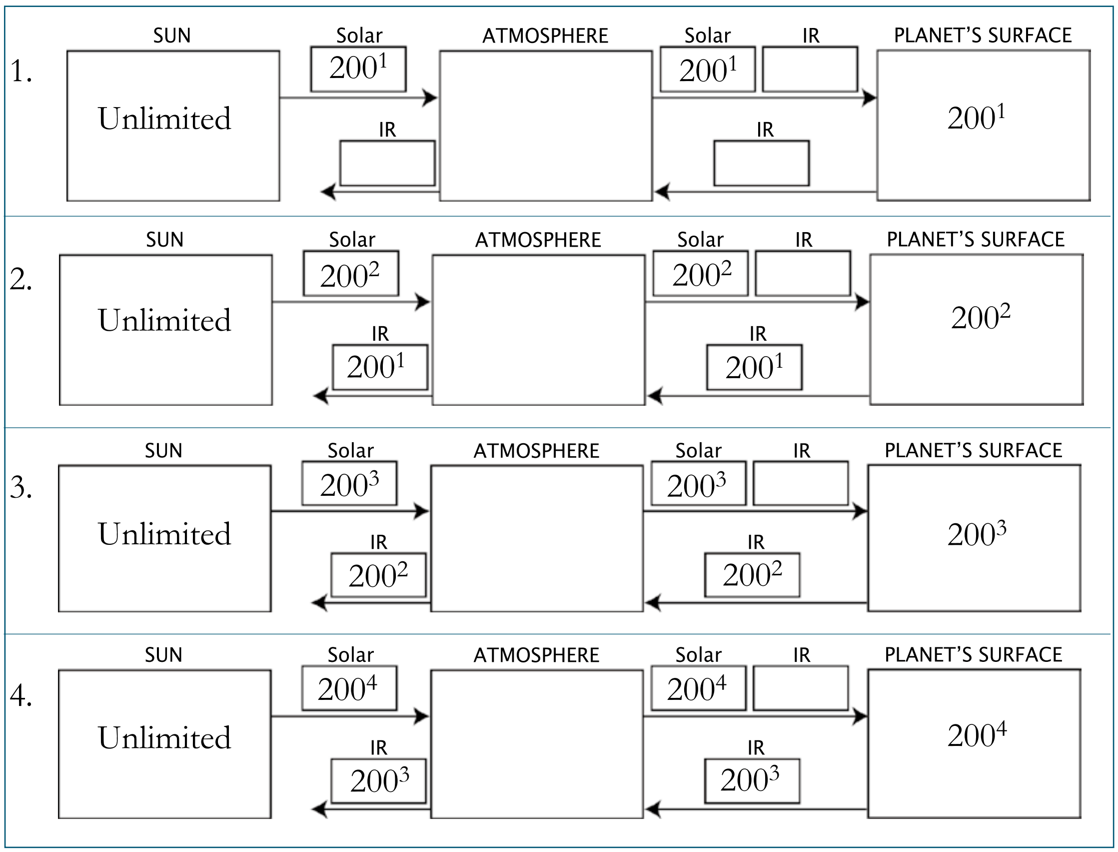
The student acting as the sun sends 2 yellow $100 bills towards the planet. (A total of 200 units reaching the planet). When the student acting as the planet's surface receives these bills, he/she changes them into 10 $20 bills, discarding the $100 bills. (These can be given back to the instructor, who can redistribute them to the various "suns" as needed.) The planet's surface holds on to the $200 in twenties until the next turn, when they will be sent out to space. (A total of 200 units leaving the planet's surface). The students should repeat the simulation for several turns until they realize what the energy relationships are in this simulation. 4 to 5 turns should be sufficient. Questions to ask during the simulation: How does the total amount of energy arriving at the surface compare to the total amount leaving the surface? What happens to the energy after it arrives at the surface? What does this do to the temperature of the surface? Have students relate the energy input and output of the planet's surface to the conservation of energy.



Sample Results for Simulation 1.

Simulation 2: Atmosphere with only Nitrogen and Oxygen

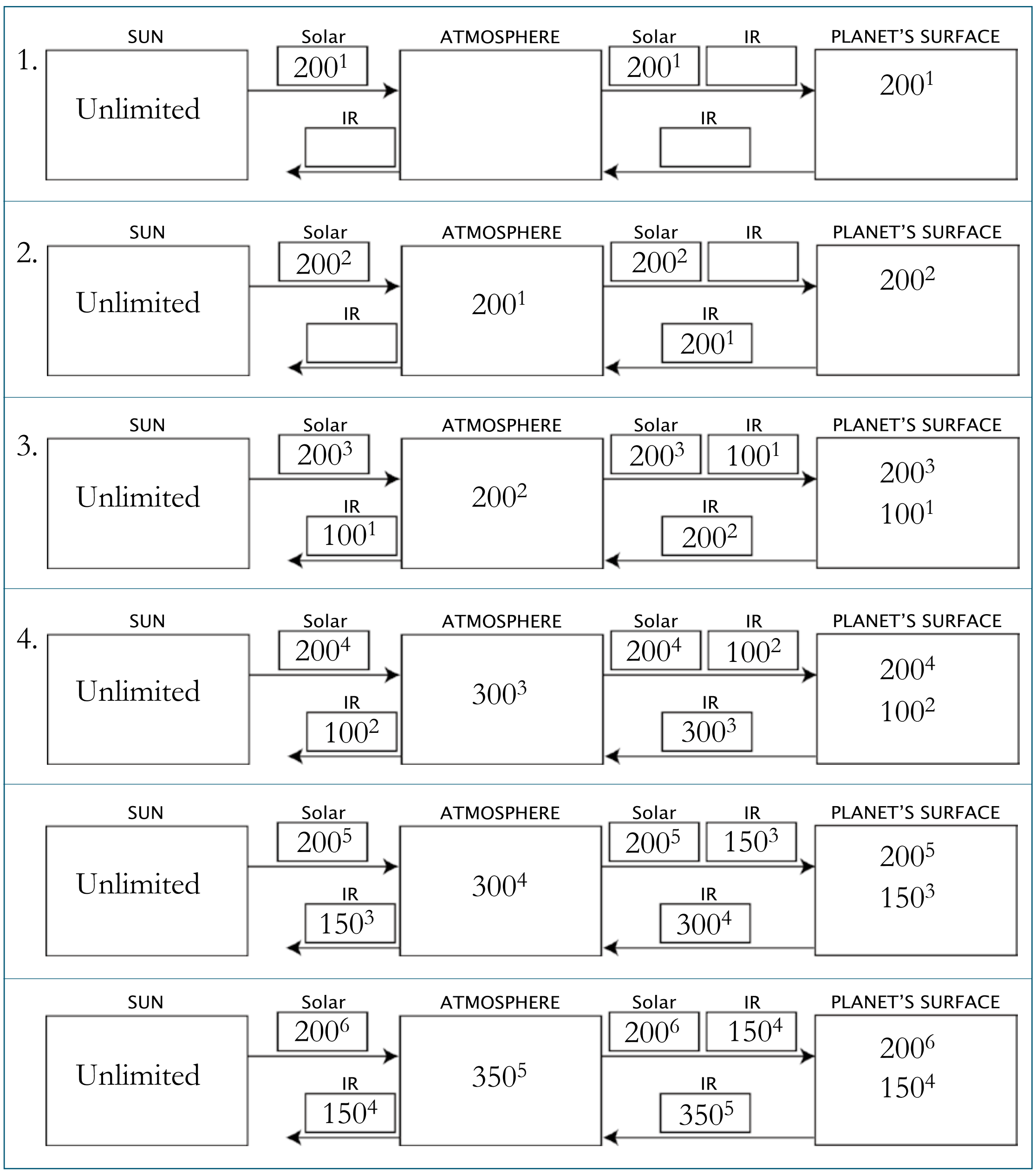
The students acting as the sun and the earth perform just as they did in the first simulation. One new student is introduced to sit between them. This student represents the nitrogen and oxygen molecules in the atmosphere. He or she observes the transactions between the original two students, but has no effect on the play money passing in either direction. Students should need three or four turns to realize the nature of the energy budget for this system. Repeat the questions from the previous simulation: How does the total amount of energy arriving at the surface compare to the total amount leaving the surface? What happens to the energy after it arrives at the surface? What effect do oxygen and nitrogen have on these processes? (Refer to these gases as being transparent to the incoming and outgoing energies/waves.) How does this affect the temperature of the surface?



Sample Results for Simulation 2.

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

Again, the students acting as the sun and the planet's surface perform as they did in the first two simulations. The students portraying Nitrogen and Oxygen molecules continue to behave as they did in the second simulation. A new student is introduced to each system to play the role of water and carbon dioxide molecules in the atmosphere. These students follow these personal instructions: intercept all infrared radiation ($20 bills), hold on to them for one turn, and then on the next turn return half of it to the planet's surface and send the other half off to space. The students may need several more turns to realize the energy budget in this system. They can stop once they realize that the earth's surface is holding more energy on a particular turn than it receives directly from the sun. Ambitious students can be supplied with additional pages for their observations (see table provided at the end of this section) and continue the simulation until there is no further increase in the energy stored in the earth's surface.



Sample Results for Simulation 3.

Repeat the previous questions: How does the total amount of energy arriving at the surface compare to the total amount leaving the surface? What happens to the energy after it arrives at the surface? What effect do the water and carbon dioxide molecules have on these processes? How does this effect differ from that of Nitrogen and Oxygen? Are water and carbon dioxide "transparent"? How does this affect the temperature of the surface? Does this effect surprise you given that there are so few of these molecules relative to the atmosphere as a whole? What do you think will happen if the simulation is carried out for more turns? Will the surface just keep getting warmer and warmer?

Consensus

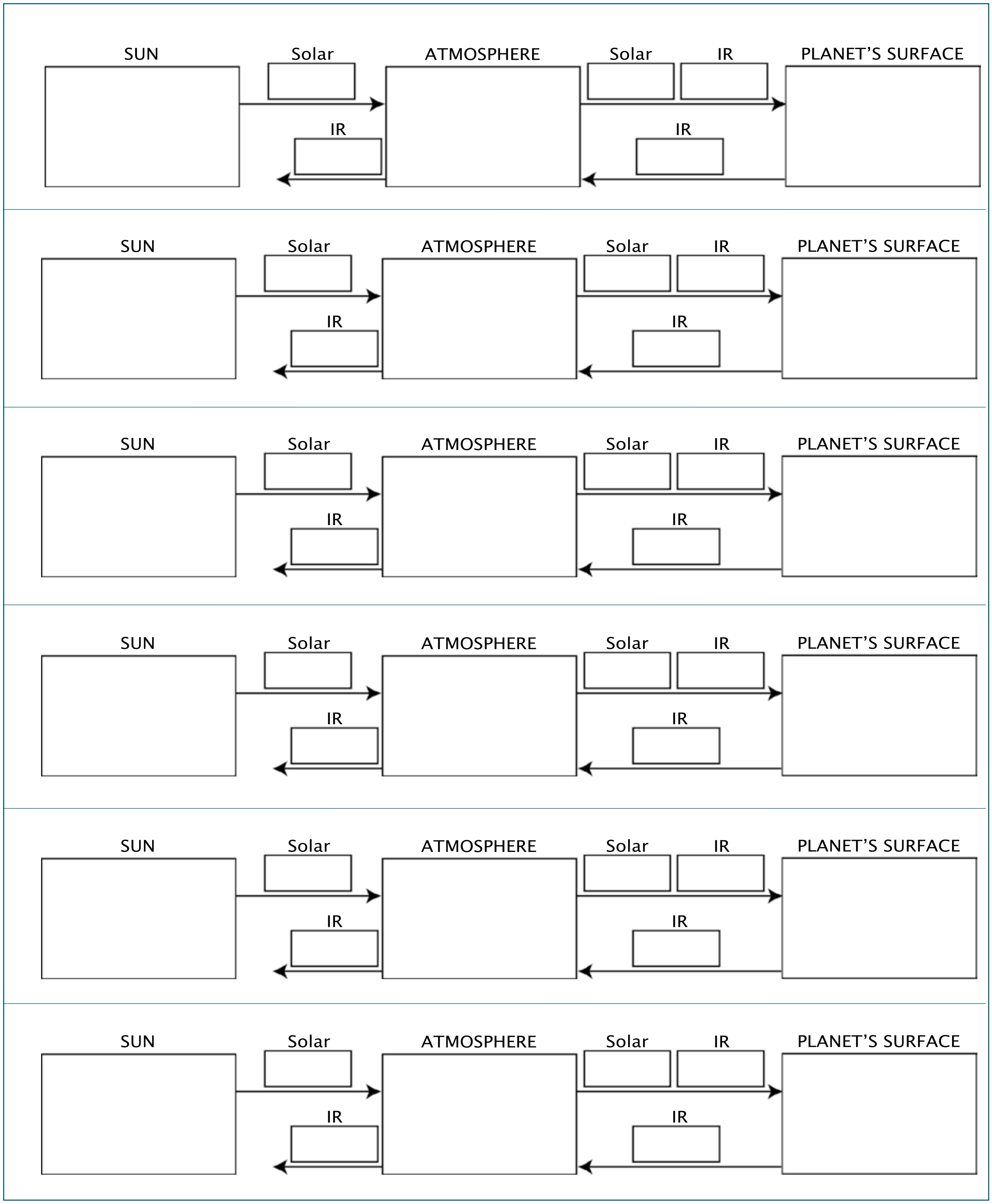
Class Period 4

Have the students summarize the results of the three simulations and relate them to the observations they made in Activity A. Their summaries should include the fact that certain gases in the atmosphere are able to absorb infrared energy/radiation and that these are the gases responsible for the greenhouse effect. They should include the fact that relatively small amounts of these gases can produce a marked greenhouse effect on a planet. Have the students arrive at a definition of the greenhouse effect based upon these summaries that all can agree upon.

Synthesis

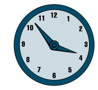
We now have a clearer understanding of how greenhouse gases are able to warm the atmosphere of a planet. Ask the students if the greenhouse effect is a benefit or a detriment to a planet? Do we need to be concerned about the greenhouse gases that human civilization contributes to Earth's atmosphere? Is it important to monitor these gases? Which human activities contribute greenhouse gases? What are some important decisions and/or choices that citizens and policy makers must make about human activities that produce greenhouse gases? Do we have sufficient information and scientific knowledge to make these decisions? What do we know and don't know? Why so you think there is such debate about these decisions? There should be a variety of answers from the students, but whatever they conclude, the instructor should ask the question, "How can we be sure?" Based on the observations so far, we cannot be sure. What can we do to improve our understanding of the ramifications of changing amounts of greenhouse gases? We could wait and see what happens, or we could try to predict the influences of these gases with our computer models. Can mathematical models simulate the greenhouse effect?

Optional Extended Turns for Simulation 3



Activity C

Can we Model the Effect of an Atmosphere Upon a Planet's Surface Temperature?


1 class period

After completing Activities A and B, students should have a clear understanding of the Greenhouse Effect. They should be aware that specific gases in a planet's atmosphere are able to absorb the infrared (heat) radiation that is emitted by the planet's surface after it has absorbed incoming solar radiation. These Greenhouse gases are the component of planetary atmospheres that enable them to produce the warming effect that students have identified when they compared theoretical planetary surface temperatures to observed temperatures. In this third activity, students will investigate the ability of computer models to simulate the Greenhouse Effect. They will utilize the information previously obtained about planetary atmospheres to predict Greenhouse factors to be used in a modified version of the *Global Equilibrium Energy Balance Interactive Tinker Toy* – mini-GEEBITT, Version B. They will then use these values to see if it is possible to obtain more realistic surface temperatures for the planets simulated by GEEBITT.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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.

Materials

Results from Activity A
Computers loaded with Microsoft Excel software. A maximum of 2-3 students per computer is suggested.
Spreadsheet *Global Equilibrium Energy Balance Interactive Tinker Toy* – Mini-GEEBITT, Version B, found at the web site http://icp.giss.nasa.gov/education

Engagement

One way to begin this activity is to have the students review what they know about the Greenhouse Effect and Greenhouse gases. A possible springboard for this discussion is to ask students to briefly write down what they think Earth would be like if there were no Greenhouse gases in its atmosphere. The students should also include an explanation of the mechanism by which the Greenhouse gases produce their warming effect. After they present their descriptions, ask them "What would the Earth be like if the amount of Greenhouse gases in its atmosphere were to be doubled?" Give them a few minutes to think about their responses, and then let them discuss the possibilities. After the discussion, remind students that global warming and the contributions of Greenhouse gases are major topics of debate within the scientific community. How can we really "know" what might happen? How can we plan for the future? Do we just have to wait and see? With their prior experience in Topics 2 and 3, at least some of the students should be able to suggest the use of computer models to make these predictions. Rather than waiting for the actual amount of Greenhouse gases in the atmosphere to double, we can try to simulate this doubling in a computer model.

Procedure

This activity is best conducted in a computer lab. After the preliminary discussion, divide the class into groups of two to three students. Have the students open their handbooks to the instructions for Activity C. Review how to start Excel on their computers, and how to load mini-GEEBITT, version B. Let the students work through the activity until they have completed table 1 and the questions following it. Have the class discuss the factors they obtained for Earth and their predictions for the other planets. Ask the students why are the values for Earth the same, but the predictions for the factors of the other planets different? Then allow the groups to work through the rest of Activity C, completing tables 2 and 3 and answering all questions.

Consensus

Students should summarize their findings by listing their predicted and best values for the Greenhouse factors for Mercury, Venus and Mars in a table on the board. Ask students how they would rate the effectiveness of mini-GEEBITT, version B for modeling planets. Is the model complete? Are the results reliable? What considerations should be made when using this model?

Synthesis

Return to the original question of the activity, what would the earth be like if the amount of Greenhouse gases in the atmosphere doubled? Ask students how they might answer this question now. How does this answer compare with their original one? Is GEEBITT a useful tool for studying planetary climates? What other questions might be answered through the use of this model?

Activity D

Can Venus and Mars Be Made Habitable?

2 class periods

Activity D may serve as an evaluation tool for Topic 4. Students use the GEEBITT model to determine if the present conditions on Venus and Mars could be modified to produce surface temperatures that would make them habitable by humans. They will have to make use of their understanding of the four factors that determine the average surface temperature of a planet and how these factors can be changed in order to decide how they might change Venus and Mars. They will have to use the GEEBITT computer model to test their hypotheses and see if habitable surface temperatures are possible. They will then have to defend their hypotheses by suggesting ways in which these changes could be implemented in reality, defending the practicality of their proposed method of terraforming. As the students develop their proposals, the teacher will be able to see how individual students grasp the concepts discussed in this module. The final presentations by student groups and the question and answer period that follows each presentation will give the students one more opportunity to display the level of their understanding of these ideas. By the end of this activity, the teacher should be able to evaluate all students' level of understanding of this topic.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ 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/or Mars.
- ✓ Debate the possibility of terraforming Mars and Venus.
- ✓ Relate the knowledge obtained from this module to the quality of humanity's future on Earth.

Materials

Computers loaded with Microsoft Excel software. A computer for each student is preferred, but a maximum of 4 students per computer will work.
Spreadsheet climate model: mini-GEEBITT, Version B found at the web site http://icp.giss.nasa.gov/education

Engagement

Class Period 1

Global warming is a topic of concern among scientists as well as the general public. There is great discussion of whether or not it is occurring, and to what extent. How much of this is due to natural fluctuations in the Earth's climate and how much is due to contributions by humanity? Is there anything we can do to alleviate the extent of the warming? What will the future bring? As students have seen, most of these questions can best be answered through the use of computer models. No one wants to, or is able to, experiment directly on Earth. Imagine a future in which Greenhouse gases run rampant on Earth, turning it into another Venus. Can this be prevented? One away to answer this is to try and come up with methods for terraforming present day Venus and Mars, making these planets more Earth-like so that they have average temperatures that would be habitable for human beings. Before considering the economic impact of attempting such a transformation, is it even theoretically possible? Are there combinations of planetary habitability factors that could terraform Venus or Mars?

Procedure

As with Activity C, this activity is best conducted in a computer lab. After the preliminary discussion described above, divide the class into groups of two to three students. Have the students open their handbooks to the instructions for Activity D. Have students summarize the four factors that affect planetary average surface temperature and describe the nature of these effects. Have the students open mini-GEEBITT, version B. Explain that they are to try and come up values for combinations of these factors that will produce habitable average surface temperatures for Venus and for Mars. Record these values (if there are such combinations) in table 1. Remind the students that they will have to present their findings when everyone has completed their work, and that they must relate the changes in the model to actual changes that could be made to the planets. Are these changes "practical?" Allow students to work on the activity for the rest of the period and to prepare their presentations.

Consensus

Class Period 2

On the second day, each team should present their findings and their conclusions. They should provide possible means of carrying out these changes to the planet. After each presentation, the other students should ask questions of the group and test their understanding of the material. As a summary of the activity, have students discuss the practicality of terraforming Venus and Mars? How viable is this idea? What implications does this have for Earth's future if the amount of Greenhouse gases in our atmosphere continues to increase? How easy will it be to reverse the effects of added Greenhouse gases? What should humanity be doing now in order to ensure continued habitability on Earth?

Synthesis

Even if we are able to terraform Venus and or Mars at some future time, it may be more economical to look for planets in other solar systems that may provide the conditions necessary for habitability by humans. Recently astronomers have identified over 50 neighboring stars that have planetary companions. The identified companions are very massive and probably would not be suitable for humans. There may be other, yet unidentified planets around these stars, that may or may not be habitable. Ask the students if they could suggest a method for identifying stars that may have habitable planets in orbits around them.

For more information:

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

http://icp.giss.nasa.gov