



Activity 1.2: Carbon, Greenhouse Gases, and Climate

Grades 10 – 12

Description:

Part 1: Modeling the Greenhouse Effect This activity demonstrates the roles that carbon dioxide, greenhouse gases, and particles in the atmosphere play in maintaining the temperature of our planet.

Part 2: Greenhouse Gases and Climate Using the Global Equilibrium Energy Balance Interactive Tinker Toy (GEEBITT version B3), a NASA data-analysis tool, students model the role of CO₂ and other greenhouse gases in moderating climate and model potential future atmospheric conditions.

Time: 3-4 class periods (for entire activity)

National Science Education Standards:

C4.a The atoms and molecules on the Earth cycle among the living and nonliving components of the biosphere.

D1.d Global climate is determined by energy transfer from the sun at and near the Earth's surface. Energy transfer is influenced by dynamic processes such as cloud cover and the Earth's rotation...

D2.a The Earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical reservoirs. Each element on Earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles.

D2.b Movement of matter between reservoirs is driven by the Earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life."

Materials:

Part 1 *Per group*

- Beaker (at least 600mL)
- 90mL vinegar in a graduated cylinder
- 3 heaping teaspoons of baking powder, divided into 3 measures
- 2 1-liter clear empty soda bottles with caps
- Spoon
- Modeling clay
- 2 thermometers
- Heat lamp
- Handouts
- Pens or pencils

Part 2 GEEBITT

- One computer for every 2-3 students, with Excel and GEEBITT loaded. You may want to put a shortcut on the desktop. (Internet access is not necessary.)
- GEEBITT Excel files (the files are available on the website, but can also be downloaded at: <http://icp.giss.nasa.gov/education/geebitt/>. This activity uses mini-GEEBITT version B3.)
- Past climatic event cards
- LCD projector (or overhead of the GEEBITT screenshots in the activity)
- Copies of the "How to Use GEEBITT" directions for each student group
- Scenario cards (there are six included here, but you may also create your own)
- Worksheets
- Pens/pencils
- Rulers



AAAS Benchmarks:

4C/H1 Plants on land and under water alter the Earth's atmosphere by removing carbon dioxide from it, using the carbon to make sugars and releasing oxygen. This process is responsible for the oxygen content of the air.

5E/M2 Over a long time, matter is transferred from one organism to another repeatedly and between organisms and their physical environment. As in all material systems, the total amount of matter remains constant, even though its form and location change.

5E/H1 At times, environmental conditions are such that land and marine organisms reproduce and grow faster than they die and decompose to simple carbon containing molecules that are returned to the environment. Over time, layers of energy-rich organic material inside the earth have been chemically changed into great coal beds and oil pools.

Guiding Questions:

- What is the role of the greenhouse effect in regulating Earth's temperature?
- How will Earth's temperature change with changing atmospheric variables?

Vocabulary

- **Earth's Atmosphere:** The layer of gases surrounding the Earth. The atmosphere protects life on Earth by absorbing light energy from the sun. The light from the sun warms the Earth, and this warmth is trapped by the Earth's atmosphere. Air is mainly composed of nitrogen, oxygen, and argon. These gases make up most of the atmosphere. Other gases are in the atmosphere in lower quantities. These gases include greenhouse gases like carbon dioxide and methane.
- **Greenhouse Gas:** A gas in an atmosphere that lets in sunlight and traps heat energy. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are carbon dioxide, methane, water vapor, and nitrous oxide.
- **Greenhouse Effect:** The ability of gases in the atmosphere to retain heat from the sun is called the greenhouse effect.
- **Reflectivity:** The percentage of sunlight reflected by the Earth's surface features (water, ice, snow, plants). Ice, especially with snow on top of it, has a high reflectivity. This means that most sunlight hitting the surface bounces back toward space. Water is much more absorbent and less reflective. So, if there is a lot of water, more solar radiation is absorbed by the ocean than when ice dominates.
- **Albedo:** The percentage of solar energy reflected from the Earth back into space. It is a measure of the reflectivity of the earth's surface.
- **Luminosity:** The total amount of light energy given off of by an object, such as a light bulb or the sun.
- **Energy Absorption:** In the case of the Earth's energy balance, it is the amount of light energy from the sun converted into heat energy absorbed by the surface features of the Earth (plants, earth, water) and its atmosphere. The energy that is not absorbed is reflected back out into the atmosphere.



- **Solar Energy:** Light and heat energy from the sun.
- **Surface Features of the Earth:** topography (landforms), bodies of water, and ground cover that cover the Earth's surface.
- **Earth's Energy Cycle/Earth's Energy Balance:** The Earth can be considered a physical system with an energy cycle that includes all incoming energy (primarily from the sun) and all losses of outgoing energy (through reflectivity). The planet is approximately in balance, so the amount of energy coming in is approximately equal to the amount going out. The Earth's energy balance is what keeps the Earth at its current temperature.

Part 1: Modeling the Greenhouse Effect

Time: One class period

Procedure:

1. Distribute the student instructions and lab questions, "Modeling the Greenhouse Effect." Give students a few minutes to read the first question and write down their ideas. Take some student answers and write them on the board.
2. Have students set up and complete their lab. Students can either answer the lab questions for homework, or you can have them answer them in class and discuss as a group.
 - Was there a difference in temperature between the bottle with the CO₂ and the control? Why do you think this was the case?
 - What do you think would happen to the final temperature if there was a higher concentration of CO₂ in the bottle?
 - Explain why the greenhouse effect is necessary for life on Earth, but why it may be a problem if the concentration of greenhouse gases increases?
3. As you discuss the lab, key points to communicate are that 1) the carbon dioxide in the bottle represents the layer of greenhouse gases (including carbon dioxide) surrounding the Earth; 2) greenhouse gases trap heat and keep the planet warm; 3) greenhouse gases are necessary for life on our planet to exist, otherwise the planet would freeze; 4) adding more greenhouse gases to the planet is like making a thicker bag, trapping more heat, and increasing the Earth's temperature.

Materials:

Part 1 *Per group*

- One plastic beaker (600mL)
- 90mL vinegar in a graduated cylinder
- 1½ tablespoons of baking powder, divided into 3 ½-tablespoon measures
- Two 1-liter clear empty soda bottles with caps
- Plastic spoon
- Modeling clay
- Two thermometers
- Heat lamp
- Handouts
- Pens or pencils



Part 2: Greenhouse Gases and Climate

Using GEEBITT, a NASA data-analysis tool, students model the role of CO₂ and other greenhouse gases in moderating climate and propose atmospheric conditions that could have produced the climates of the past.

Time: Two to three periods. You can start the activity while the lab is sitting.

Guiding Questions:

- What are the factors that contribute to maintaining the Earth's temperature?
- How are these factors affected by greenhouse gases?
- What is the impact of increased greenhouse gases on the Earth's temperature?

Notes: There are three levels of GEEBITT climate model from simple to complex. All three versions are available on the curriculum website. Depending on the level of your students and how much detail you plan to go into on the different types of greenhouse gases and their sources, you will want to choose either MiniGEEBITT B3, which models light intensity (e.g. distance from the planet and sun's luminosity), albedo, and absorbing atmosphere (e.g. greenhouse factor). Alternatively, you can choose the full GEEBITT version, which adds aerosols, clouds, tropospheric, and stratospheric components by their sources. The activity for MiniGEEBITT B3 is included here.

Materials:

Part 2 GEEBITT

- One computer for every two to three students, with Excel and GEEBITT loaded, you may want to put a shortcut on the desktop. (Internet access is not necessary.)
- GEEBITT Excel files (the files available on the website but can also be downloaded at: <http://icp.giss.nasa.gov/education/geebitt/>)
- Past climatic event cards
- LCD Projector (or overhead of the GEEBITT screenshots in the activity)
- Copies of the "How to Use GEEBITT" directions for each student group
- Scenario cards (there are six included here, but you may also create your own)
- Worksheets
- Pens/pencils
- Rulers

If you don't have time to work through the GEEBITT simulation, there is a very nice web-based greenhouse gas simulator published by the Physics Education Technology Project online at <http://phet.colorado.edu/en/simulation/greenhouse>. It allows students to modify greenhouse gas concentrations and number of clouds, and provides preset examples for today, an ice age, and 1750. It shows temperature change in Kelvin, Fahrenheit, and Centigrade, and provides graphical and numerical illustrations of sunlight and infrared light as they enter and escape the Earth's atmosphere. It also models "layers of glass" simulating the "greenhouse effect." Finally it lets you build atmospheric concentrations of a variety of gases including CH₄, CO₂, H₂O, N₂, and O₂, and modify the amount of visible and infrared light entering the atmosphere. Please note that this resource requires at least version 1.5 of Java Applet Plug-in.

Pre-Activity

- Familiarize yourself with the miniGEEBITT v.B3 simulation and how it works.
- Copy the miniGEEBITT v.B3 excel file to all the computers you plan to use.
- Make copies of the "How to use GEEBITT" directions for student groups.



Procedure:

Part 1:

1. Tell students that now that they have seen the greenhouse effect in action in the lab, they are going to use a computer model to make predictions about what the Earth's temperature will do in the future given different greenhouse gas emissions scenarios. (NOTE: because this is a simple model, feedback loops and other anomalies will not be represented in the results of the simulation.)
2. The first thing they will need to do is calculate what CO₂ concentrations will be like if everything stays the same. Ask students to think about the greenhouse gas lab. Ask them what CO₂ has to do with temperature.
3. Project the graph of CO₂ concentrations from 2005 to 2010 and explain that it illustrates the increase in the amount of CO₂ in the atmosphere over the past five years. Ask students what trend they see. They are going to use this graph to describe the trend numerically, so that they can predict what CO₂ concentrations may do in the future.
4. Hand out the "Earth Temperature Simulation Part 1: Calculating CO₂ increases" worksheet. **NOTE:** Depending on the level of your students and time limitations, you may want to complete this as a whole class activity, have students work in groups, or assign this portion of the activity for homework.

Part 2:

1. Project the GEBITT spreadsheet and discuss each of the components of the program (see detailed directions and handout below) and demonstrate how to use the model. You may want to spend extra time on this if your students are not familiar with Excel. Explain how each of the four variables contributes to the model's calculation of the planet's average temperature.
2. Ask students, what they think would happen to the temperature if the sun produced more energy? Less energy? What would happen if the Earth were closer to the sun? Farther away? Use other planets as examples. Mercury, for instance, is much hotter than the Earth and Neptune is much colder.
3. Now remind students of their Earth's energy balance activity. Ask students what happens to the sun's energy when it gets to the Earth? Explain that the albedo variable represents the amount of energy reflected by the Earth's surface and the greenhouse factor represents all the components in the atmosphere that absorb the sun's energy – what they modeled when they did their greenhouse gas lab.
4. Tell students that by modifying these factors in the model, students will be able to see what the Earth's temperature would be like in different future emissions scenarios.
5. Students can do this independently or in groups. Break students into groups of two to three per computer and hand out GEEBITT directions, *Earth Temperature Simulation Part 2:*



CHICAGO BOTANIC GARDEN

Predicting Temperature Change, and one scenario card per group or per student depending on their knowledge level.

6. Have students open the GEEBIT program (you may want to create icons on the desktop for easy access) and follow the directions on the worksheet.
7. Once students have completed their scenarios, have them come back together as a class to discuss their results. What did they find out about how different levels of reflectivity and heat retention affect temperature? Did one variable impact temperature more than the other? Did it make a difference if they used both variables?
8. To summarize – clearly temperature is affected by greenhouse gases, but what about the other factors that make up climate – precipitation, winds, water? They will explore those in coming days.



Name: _____ Date: _____ Room: _____

Modeling the Greenhouse Effect

Make a prediction: Carbon dioxide and other gases form the atmosphere surrounding the Earth. These gases and particles let light from the sun reach the Earth's surface, but do not let heat energy escape. Predict how this might affect the Earth. What would happen if the concentration of CO₂ in the atmosphere increased? Decreased?

Materials:

- One plastic beaker (600mL)
- 90mL vinegar in a graduated cylinder
- Three heaping teaspoons of baking powder, divided into three measures
- Two 1-liter clear plastic soda bottles with caps
- Funnel
- Plastic spoon
- Modeling clay
- Two thermometers
- Heat lamp
- Handouts
- Pens or pencils

Procedure:

Part 1: Creating Carbon Dioxide

1. Label one soda bottle "Control" and one "CO₂"
2. Fill your beaker with 30 mL of vinegar
3. Add 1 teaspoon of vinegar
4. Let the mixture bubble undisturbed
5. Because carbon dioxide is heavier than air, you can pour it like you pour liquid. When the mixture is done bubbling, put the funnel in the top of the soda bottle labeled "CO₂" and pour the carbon dioxide created by the baking powder/vinegar reaction into the funnel and into bottle. Do NOT pour in any of the liquid.
6. Cap the bottle.
7. Repeat steps 1-6 two more times.



Part 2: Measuring Temperature

1. In the “Control” bottle, put in one of the thermometers and seal the opening around it with the modeling clay, making sure that the opening is fully covered.
2. Take the cap off the “CO₂” bottle, put in the other thermometer and seal the opening carefully with modeling clay, making sure the opening is fully covered. This is important because it prevents any of the CO₂ you added to the bottle from escaping out the top.
3. After letting the bottle sit for two minutes, record the starting temperature in both bottles in your data table next to the Baseline time.
4. Put both bottles under your heat lamp. Record the temperature in each bottle every 30 seconds for 5 minutes. Record the temperatures in your data table.

Data table:

Time	Control Temp	CO₂ Temp
Baseline		
30 sec		
1.0 min		
1.5 min		
2.0 min		
2.5 min		
3.0 min		
3.5 min		
4.0 min		
4.5 min		
5.0 min		
Temperature Change		

Answer the following questions in your lab notebook:

1. Graph your data.
2. Describe the general trend your temperatures took over the observation period.
3. What happened to the heat and light from the lamp in the each bottle?
4. What was the difference in temperature change in your control and in the bottle with CO₂?
5. What is the effect of CO₂ on temperature?
6. What effect did adding CO₂ have on the heat trapped in the bottle?
7. Explain why the greenhouse effect is necessary for life on earth, but why it may be a problem if the concentration of greenhouse gases increases?
8. Consider your experiment. Are there things about the experiment that could have affected your results? Explain what they are and how to change the experiment to address any problems.



DIRECT MEASUREMENTS: 2005-PRESENT

Data source: Monthly measurements (corrected for average seasonal cycle).
Credit: NOAA





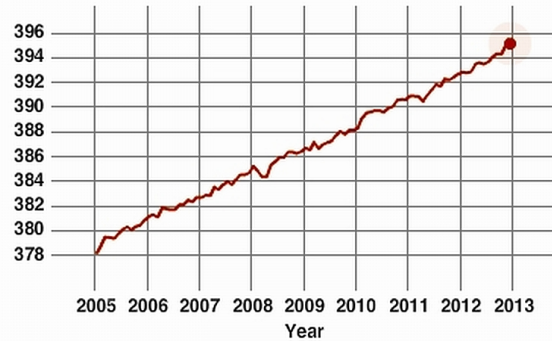
Name _____ Date _____ Class _____

Earth Temperature Simulation Part 1: Calculating CO₂ Increases

1. Calculate the current approximate rate of increase in CO₂. The slope represents the current rate of increase over time. Show your work.

DIRECT MEASUREMENTS: 2005-PRESENT

Source: Monthly measurements (corrected for average seasonal cycle). Credit: NOAA



2. Use the slope to estimate the amount of CO₂ that would be in the atmosphere in:

For every (X) _____ year(s), (Y) CO₂ increases by _____ ppm

2020 CO₂ _____ ppm, an increase of _____ % from 2010.

2100 CO₂ _____ ppm, an increase of _____ % from 2010.

2500 CO₂ _____ ppm, an increase of _____ % from 2010.

To calculate percent increase from 2010:

- Identify the CO₂ concentration in 2010.
- Subtract the 2010 CO₂ concentration from the CO₂ concentration in each prediction year.
- Divide the difference by the 2010 CO₂ concentration.

3. What would happen to the graph if we added CO₂ to the atmosphere more quickly? Less quickly? Explain your answer.



Name _____ Date _____ Class _____

Earth Temperature Simulation Part 2: Predicting Temperature Change

Use the GEEBIT model to answer the following questions. Refer to the GEEBITT instruction packet provided by your teacher to guide you.

4. Modeling the Earth's current climatic conditions

a. Open the GEEBITT model using the icon on your desktop

b. Calculate the sun's energy that reaches the Earth (the black planet model)

- i. Click on Sheet 1. Read the information on the spreadsheet and find where it tells you the values for:
 - (1) the sun's energy output (luminosity)
 - (2) the Earth's distance from the sun in astronomical units
- ii. Enter these two values in the gray boxes in sheet 1.

c. Add surface features to your model

- i. Click on Sheet 2. Read the information on the spreadsheet and find where it tells you the values for the Earth's albedo (the energy reflected by the Earth's surface features)
- ii. Enter this value in the gray box in sheet 2

d. Add the atmosphere to your model

- i. Click on Sheet 3. Read the information on the spreadsheet and find where it tells you the values for the Earth's greenhouse factor (the amount of heat absorbed by the atmosphere)
- ii. Enter this value in the gray box in sheet 3

You will know you are right when the Earth's average temperature with albedo and the greenhouse factor (shown on sheet 3) = 15° C (58.9° F).

5. Predicting Future Temperature Changes

Refer back to part 1, question 2, and write the percentage increases you calculated earlier below. Use the GEEBITT model to calculate the Earth's average temperature at each date using the estimates you calculated.

- a. First convert the percentage to decimal form (90% = .90).
- b. Add this number to the Earth's current greenhouse factor (1.00).
- c. Enter the decimal form in the greenhouse factor data entry box on Sheet 3.
- d. Record the temperature below.

2020 shows an increase of _____ % in CO₂ from 2010. Temperature would be _____ C.

2100 shows an increase of _____ % in CO₂ from 2010. Temperature would be _____ C.

2500 shows an increase of _____ % in CO₂ from 2010. Temperature would be _____ C.



Name _____ Date _____ Class _____

Earth Temperature Simulation Part 3: Modeling Changes

Use the information on your situation card to complete the chart. Calculate what the Earth's temperature would be in your scenario using GEEBITT. First calculate each cause and its effect separately. Then calculate them both together. Fill in the table below.

Cause	Effect	Temperature	
		Celsius	Fahrenheit
1.	1.		
2.	2.		
Combined Temperature Change Effects			



How to use MINI-GEEBIT (Version B3)

The Global Equilibrium Energy Balance Interactive Tinker Toy

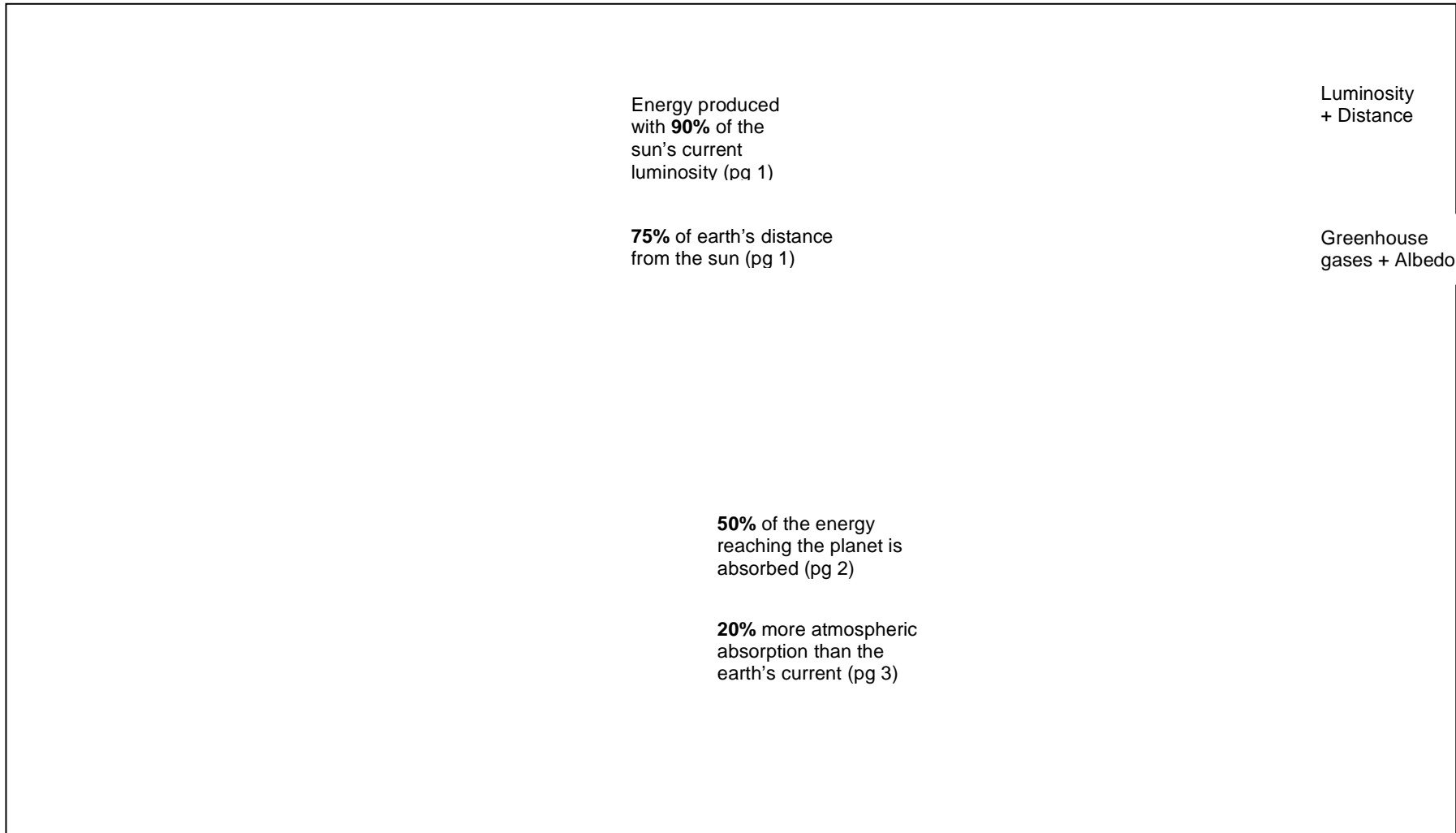
Variables (Change the four variables below to create different climate scenarios)

1. **Luminosity (light intensity) of the planet's sun** (sheet 1). Luminosity can be changed to reflect different light intensities. The default luminosity of the sun is 1 (100 percent of the sun's current observed value). For example, entering 0.5 will produce a luminosity that is 50 percent of our sun's current luminosity.
2. **Distance from the planet's sun** (sheet 1). The units for the distance must be in Astronomical Units (AU). A table is provided with the average distances of the planets in our solar system - in meters and in astronomical units.
3. **Albedo (reflectivity) of the planet's surface** (sheet 2). Albedo models the planet's surface reflectivity. Values must be between 0 (no energy is reflected) and 1 (100 percent energy is reflected). The default value is 0 - all the incoming energy is absorbed. This corresponds to a "black body," which is a planet with no surface features or atmosphere. A table is provided with the observed albedos of the planets in our solar system.
4. **Absorption effect of the planet's atmosphere** (sheet 3). The "Greenhouse Factor" models the heat absorption capacity of the atmosphere. This variable simulates the ability of greenhouse gases to absorb thermal energy being emitted by the planet's surface and radiate some of that energy back to the surface. The default value is 1 - Earth's current absorption rate.

Format (Color codes indicate cell functions)

- **Green Cells** are **notes, information, or explanations** and should be read before using the page. The pale green cells are reserved for data.
- **Gray Cells** are **input boxes** where you change the values of the variables. Hit enter to see the resulting changes in the spreadsheet.
- **Yellow Cells** are either **energy sources or energy arriving** at the planet. The pale yellow cells represent concepts that can be changed on that page. The maximum and average energy arriving at each square meter of the planet's surface each second are given separately. The maximum energy corresponds to the energy that would arrive each second on a surface that is perpendicular to the sun's rays. The average energy refers to the average amount of energy hitting every square meter of the planet's surface, including all those areas not perpendicular to the rays.
- **Blue Cells** show the **numerical results of calculations**. This is either an amount of energy or a temperature. *Dark blue* cells are results for black body, a planet with no surface features or atmosphere. *Medium blue* cells are results for a planet that has surface features (albedo). *Light blue* cells are results of a "fully featured" plane with surface albedo and an absorbing atmosphere. On sheets 1 and 2 there are *additional light blue boxes* in the upper right side that show temperature due to the effect of all the variables. They allow you to set albedo and/or absorption, then vary the distance or luminosity and observe the effect upon the average temperature.

SAMPLE GEEBITT MODEL





Name TEACHER ANSWER SHEET Date _____ Class _____

Earth Temperature Simulation Part 1: Calculating CO₂ increases

1. Calculate the current approximate rate of increase in CO₂. The slope represents the current rate of increase over time.

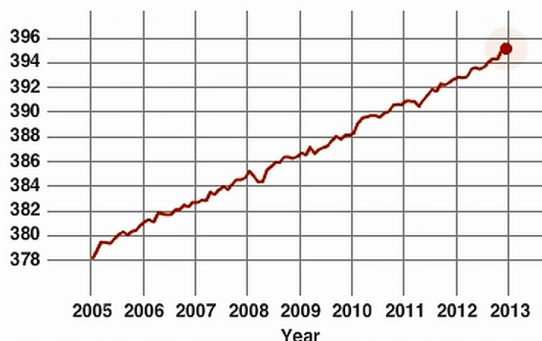
- e. Draw one straight line that covers as many data points as possible.
- f. Identify two points on the line and use the graph to estimate their value.
- g. The first is (X₁, Y₁) and the second is (X₂, Y₂).
- h. Use the equation to calculate slope.

$$\text{Slope} = \frac{Y_2 - Y_1}{X_2 - X_1}$$

$$\text{Slope} = \frac{2}{1}$$

DIRECT MEASUREMENTS: 2005-PRESENT

Source: Monthly measurements (corrected for average seasonal cycle). Credit: NOAA



2. Use the slope to estimate the amount of CO₂ that would be in the atmosphere in:

For every (X) 1 year(s), (Y) CO₂ increases by 2 ppm

2020 CO₂ 408 ppm, an increase of 5 % from 2010.

2100 CO₂ 568 ppm, an increase 46 % from 2010.

2500 CO₂ 1368 ppm, an increase of 253 % from 2010.

To calculate percent increase from 2010:

- Identify the CO₂ concentration in 2010.
- Subtract the 2010 CO₂ concentration from the CO₂ concentration in each prediction year.
- Divide the difference by the 2010 CO₂ concentration.

3. What would happen to the graph if we added CO₂ to the atmosphere more quickly? Less quickly? Explain your answer.



Name TEACHER ANSWER SHEET Date _____ Class _____

Earth Temperature Simulation Part 2: Predicting Temperature Change

4. First, use the How to Use MINI-GEEBIT instructions to set up the spreadsheets to correspond to Earth's current conditions.

- a. On sheet 1 find and input in the gray boxes
 - i. the sun's energy output (luminosity) 1.00
 - ii. the Earth's distance from the sun in astronomical units 1.00
- b. On sheet 2 find and input in the gray box
 - the Earth's albedo (surface reflectivity) 0.306
- c. On sheet 3 find and input in the gray box:
 - iii. the Earth's greenhouse factor (atmospheric heat absorption) 1.00

You will know you are right when the Earth's average temperature with albedo and the greenhouse factor (shown on sheet 3) = 15 C (58.9 F)

5. Refer back to part 1, question 2, and write the percentage increases you calculated earlier below. Use the GEEBITT model to calculate the Earth's average temperature at each date using the estimates you calculated.

- a. First, convert the percentage to decimal form.
- b. Go to sheet 3 and enter the decimal form.
- c. Record the temperature below.

2020 shows an increase of 5 % in CO₂ from 2010. Temperature would be 16.6° C.

2100 shows an increase of 46 % in CO₂ from 2010. Temperature would be 27.2° C.

2500 shows an increase of 254 % in CO₂ from 2010. Temperature would be 638.8°C.

6. Use the information on your situation card to complete the chart. Calculate what the Earth's temperature would be in your scenario using GEEBITT. First calculate each cause and its effect separately, and then calculate them both together. Fill in the table below.

Cause	Effect	Temperature	
		Celsius	Fahrenheit
1. Answers will vary	1. Answers will vary		
2. Answers will vary	2. Answers will vary		
Combined Temperature Change Effects			