Modeling Early Earth Climate with GEEBITT
In-class Exercise and Homework

Author
Cindy Shellito
Earth Sciences Program, University of Northern Colorado
Email: Lucinda.shellito@unco.edu

Background
The rising level of greenhouse gases in the atmosphere is a growing concern in the 21st century and receives much attention in the media. As you have read in the assigned articles and in your text, variable levels of atmospheric greenhouse gases have likely played an important role in climate change since the formation of Earth's atmosphere. In this exercise, you will use a simple climate model to examine the importance of greenhouse gas forcing on climate in relation to two other forcing factors: the solar energy received by the sun, and Earth's albedo.

Assignment Objectives
- Compare the roles of solar luminosity, planetary albedo, and the greenhouse effect in determining the climate of the Early Earth and that of the present.
- Practice using a simple Energy Balance Model (EBM) to used to examine climate sensitivity.

The TOOL:
The Global Equilibrium Energy Balance Interactive Tinker Toy (GEEBITT) is an Excel-based climate model made available by the NASA Goddard Institute for Space Studies. This is a 1-dimensional energy balance model (EBM) that calculates global mean surface temperature, based on a planet's distance from the sun, solar luminosity, global albedo, and a parameterized 'greenhouse-factor' (we will call 'GHF').

STEP 1: Familiarize yourself with GEEBITT

Download and open the Excel file containing GEEBITT (Mini-GEEBITT Version B) from the NASA GISS website:
http://icp.giss.nasa.gov/education/geebitt/
The first Excel worksheet contains a full description of Mini-GEEBITT. Take a look at each of the three remaining sheets. Each sheet allows you to tinker with global parameters to explore the effects of each on surface temperature.

(1) Go to Worksheet 1.

Calculate the 'black-body' temperature of one of the other planets listed in the table.

Planet:_______________

Distance from sun (AUs):_________________

Black Body Temperature:_________________

Should you change solar luminosity, if you are considering the climate of another planet? Why or why not?

(2) Go to Worksheet 2.

Calculate the new 'black-body' temperature of your planet using the recommended albedo.

Albedo: _____________________

Black Body Temperature: ___________________

(3) Go to Worksheets 3.

Here, explore the effects of the Greenhouse Factor (GHF) on your chosen planet. The GHF is a shortcut method of parameterizing the effects of gases on Earth's surface temperature.

What is the temperature of your planet if GHF =1.0? ______________________

At what value of the GHF will the temperature of this planet be comparable to that of Earth (59°F)? (Note: On some planets, you will not be able to obtain a temperature comparable to Earth! If you find this is the case with your chosen planet, provide a brief explanation why.)

___

___

STEP 2: Explore Earth's Modern Climate Sensitivity

Each question below requires you to conduct a simple experiment with GEEBITT. In addition to answering the questions, record the parameters and result from each experiment in the table provided at the end of this document.

(1) Given the present-day albedo of Earth (0.306), and present-day level of greenhouse gases (GHF=1.0), at what value (approximately) do you need to set the *solar luminosity factor* to freeze the planet? (Don't forget to reset the 'Distance' to 1 A.U.!)

(2) Now, reset the solar luminosity factor to 1.00. At what value do you need to set the GHF in order to freeze the planet?

(3) Global climate models suggest that a doubling of CO_2 in the atmosphere (from present level of 370 ppm) will increase global mean temperature by 3°C. By how much do you need to increase the GHF to increase temperature by 3°C?

(4) Because temperature becomes less sensitive to additional pCO_2 the higher the initial concentration of CO_2, it is estimated that an *additional* doubling of CO_2 (to ~1480 ppm) will only increase surface temperature by another 3°C. By how much do you need to increase the GHF to increase temperature by another 3°C?

STEP 3: Modeling Archean Hot-House and Snowball Earth Scenarios

ARCHEAN EARTH

In the Archean, solar luminosity was ~70-80% of what it is today. Albedo may have varied, depending on surface type. Answer the following questions. Again, record any GEEBITT experiments in the table provided.

(1) Based on your reading and/or class discussion about the factors that affect albedo, what global albedo might you use to represent the land surface in Archean Earth? Explain your answer.

(2) Set up GEEBITT to calculate a surface temperature for Archean Earth, based on 70% solar luminosity and your estimated albedo above.

What is the temperature of Earth if GHF=1.0?______________________

What value of the GHF is necessary to make the surface temperature comparable to that of modern Earth (59°F)?

____

At what value of GHF will the global mean temperature fall below freezing?

____

At what value of GHF will global mean temperature rise to 40°C (temperature at which methanogenic bacteria thrive)?

____

SNOWBALL EARTH

During the Neoproterozoic, solar luminosity was about 94% of what it is today.

(1) Based on your reading and/or class discussion, what albedo might you use to represent the land surface of Snowball Earth? Explain your answer.

(2) Set up GEEBITT to calculate the surface temperature of Snowball Earth based on the reduced luminosity and your estimated albedo.

By how much do you need to increase the GHF from present level (1.0) to warm the Earth above freezing temperatures?

____

Based on your analysis of the GHF for modern day, what does this imply about the magnitude of greenhouse gas emission necessary for deglaciation?

____

____

(3) Set GHF =1.0. How sensitive is the surface temperature in the Snowball Earth scenario to a 10% change in albedo (i.e., how many degrees C does temperature change for every 10% change in albedo)? To help you answer this question, perform a series of calculations with GEEBITT, record your results in the table provided, then plot albedo vs. surface temperature.

<u>Synthesis questions (Answer the following on a separate sheet of paper and turn them in for your homework):</u>

(1) Which of the following plays the biggest role in modulating Earth's surface temperature: a 10% change in luminosity, a 10% change in albedo, or a 10% change in the GHF? *(Make plots, similar to the one you made above).* Do you think this is representative of the factor that has the greatest overall effect on climate? Why or why not?

(2) What, do you suppose, are the limitations of using the GHF as a parameterization for the effects of greenhouse gases on global surface temperature?

(3) List some improvements that you think would make this model a more realistic representation of the climate system. What other climate forcing factors (at minimum) do you think could be included in a one-dimensional EBM?

Scenario (Modern, Snowball, or Archean)	Luminosity Factor	Albedo	GHF	Temperature