Student Activity Sheet: Climate Modeling (Computer Spreadsheet Model)

Introduction: The notion of climate involves an average of daily weather associated with the temperature, wind, cloudiness, and precipitation in a particular location. The period of time averaging can vary from months to years or a decade. The climate system comprises, besides the atmosphere, the hydrosphere (liquid water), the cryosphere (snow and ice), the surface lithosphere (solid Earth) and the biosphere (plant and animal life).

Climate models at various levels of sophistication have been developed to represent this system and its variations. The simplest model is the zero-dimensional *energy balance model (EBM).* It relies on the global average radiation budget at the top of the atmosphere and provides a mean global surface temperature. At the opposite extreme from these simple models is *the general circulation model (GCM),* which includes a complete description of the atmosphere on a three-dimensional grid and is usually coupled with an *oceanic circulation model (OCM),*

In this activity, a type of EBM in a spreadsheet format is used which allows you to see what effect the changing of one or more of the variables will have on the average temperature of the Earth's atmosphere. Temperature is determined from the solar input, atmospheric absorption of longwave radiation from the Earth and albedo (reflectivity). Quantities can be changed independently or together to see the effects on temperature.

The greenhouse effect is the absorption of infrared radiation from the Earth's surface by certain gases in the atmosphere. Carbon dioxide and water vapor are the main greenhouse gases. Increased CO_2 may or may not increase the Earth's temperature because of the many feedback mechanisms, both positive and negative, that are involved. If a warming does occur, then it is known as *global warming.* Some of the feedback mechanisms involved are:

1. **As we emit more CO_2 into the atmosphere, more infrared radiation (IR) is absorbed, and the Earth should warm by approximately 1.1 degrees K.**

2. **If the Earth warms, then more H_2O would evaporate and the increased water vapor would absorb more IR radiation, warming the Earth even more. The absorptivity of the atmosphere would increase in a positive feedback, possibly increasing the temperature by as much as 0.6 degrees K.**

3. **If there is more water vapor in the atmosphere, more low clouds may form, increasing the absorptivity of the atmosphere and causing more heating, possibly as much as 2.2 degrees K.**

4. **Heating of the atmosphere could cause ice and snow in polar regions to melt. Since ice and snow have high albedo, less ice and snow would represent a positive feedback by allowing more warming and increasing temperature by 0.5 degrees K.**

5. **Since high clouds reflect more incoming solar energy, more high clouds would mean increased albedo. This would serve as a negative feedback and have a cooling effect, causing a temperature decrease of as much as 1.5 degrees K.**

John F. Mitchell in his 1989 article in the ***Review of Geophysics,*** " The Greenhouse Effect and Climatic Change", has identified how much warming could occur by each of the factors mentioned above as a result of a doubling of the CO_2 concentration in the atmosphere. The movement of energy within the Earth/atmosphere/ocean system becomes increasingly more complex as many additional feedback mechanisms mentioned here are engaged. These interactions are very complicated and redundant, that is, one factor influences another factor, which influences the first factor and so on. This tendency makes predicting climate change very difficult and requires the use of the world's largest and fastest computers to produce even semi-realistic models.

Objective:

- To model the relationship between certain variables in the Earth system affecting climate;
- To use a spreadsheet model to test hypotheses about how changes in the Earth's temperature and energy balance will affect the Earth's temperature
- To learn about the processes and interactions involved in maintaining the Earth's energy balance and gain an appreciation for their complexity;
- To learn about and appreciate computer modeling as an investigative tool;

Important Terms: Climate, computer spreadsheet, global warming, climate model, energy balance, greenhouse effect, albedo, CO_2, atmospheric absorption, water vapor, EBM, GCM, OCM, positive or negative feedback;

Materials: Copy of **Student Activity Sheets, Climate Modeling Spreadsheet,** pencil/paper, calculator, colored pencils, graph paper; **OR** PC/MAC computer with spreadsheet capability (Excel, Excess, etc.);

Procedure:

1. Read over and discuss the **Introduction.**

2. Review concepts such as the Earth's heat budget, energy balance and electromagnetic radiation.
   - Pay particular attention to the relationship between incoming solar energy and the atmospheric gases with heat absorbing capabilities.

3. Review the **Data Table: CLIMATE MODEL #1 and the Information Tables pertaining to it.**
   - Be sure that you understand the symbols and formulas that you will be using to complete each column in the spreadsheet that you chose.

4. Fill-in the empty columns (A,B and C) of the spread sheet using the designated formulas and your calculator/computer.

5. Complete the Enrichment activity.

6. Answer the **Analysis and Comprehension** questions.

NOTE: Each person will be required to submit:

1. Completed spreadsheet,
2. Completed Enrichment Activity
3. Completed Analysis and Comprehension questions.

ENRICHMENT ACTIVITY

Create 3 graphs:

- Temperature vs. solar constant,
- Temperature vs. albedo
- Temperature vs. atmospheric absorptivity.

(If you have a computer graphing program, put all 3 on the same graph. If you are working the calculations with a calculator, create your own graphs on graph paper.)

INFORMATION TABLES

INFORMATION TABLE #1:

DATA TABLE SYMBOLS AND VALUES

SYMBOL	MEANING	VALUE
T_E	Surface temperature of the Earth	Variable
R	Amount of energy coming from Earth	Variable
σ	Stefan-Boltzman constant	5.67×10^{-8} W/m^2K^4
α	Albedo of the Earth	0.30 (at current conditions)
a	Absorptivity of the atmosphere	0.77 (at current conditions)
S	Solar constant	1368 Wm^2
K	Temperature in degrees Kelvin (K)	Variable

INFORMATION TABLE #2:

FORMULAS FOR COLUMNS A,B AND C:

STEP #1: To compute surface temperature (T_E) for Column A: $(R / \sigma)^{1/4}$
STEP #2: To convert K to ° C in Column B: ° C = K - 273.15
STEP #3: To convert °C to °F in Column C: ° F = 9/5 °C + 32

Student Activity Sheet #1

DATA TABLE: CLIMATE MODEL #1

	A	B	C	D	E	F	G
	Surf. Temp. (K)	° C	° F	R (Wm^{-2})	Solar Constant S	Albedo α	Atmos. Absorption a
1				387.8	1363.000	0.300	0.770
2				388.1	1364.000	0.300	0.770
3				388.4	1365.000	0.300	0.770
4				388.7	1366.000	0.300	0.770
5				389.0	1367.000	0.300	0.770
6				389.3	1368.000	0.300	0.770
7				389.6	1369.000	0.300	0.770
8				389.8	1370.00	0.300	0.770
9				390.1	1371.00	0.300	0.770
10				362.5	1372.00	0.350	0.770
11				355.9	1368.00	0.360	0.770
12				350.3	1368.00	0.370	0.770
13				344.8	1368.00	0.380	0.770
14				339.2	1368.00	0.390	0.770
15				333.7	1368.00	0.400	0.770
16				305.9	1368.00	0.450	0.770
17				389.3	1368.00	0.300	0.770
18				389.3	1368.00	0.300	0.770
19				389.3	1368.00	0.300	0.770
20				389.3	1368.00	0.300	0.770
21				389.3	1368.00	0.300	0.770
22				374.1	1368.00	0.300	0.720
23				377.0	1368.00	0.300	0.730
24				380.0	1368.00	0.300	0.740
25				383.0	1368.00	0.300	0.750
26				386.1	1368.00	0.300	0.760
27				389.3	1368.00	0.300	0.770
28				392.5	1368.00	0.300	0.780
29				395.7	1368.00	0.300	0.790
30				399.0	1368.00	0.300	0.800

Student Activity Sheet #2

ANALYSIS ANC COMPREHENSION

1. What do the following symbols represent?

a. α _____ b. S _____

c. R _____ d. a _____

e. K _____ f. T_E _____

2. Why is it necessary to use $(\frac{1}{4})$ when computing the Earth's solar constant?

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3. What 3 pieces of information are needed in an EBM to calculate the surface temperature of the Earth? _____

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4. Why is the effect of CO_2 increases in the atmosphere on the Earth's temperature not definite? _____

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5. When does the concept of global warming come into play? _____

_____

6. Draw a simple diagram of feedback scenario #2.

7. Describe the uncertainty of the effect of different types of clouds on the energy balance? _____

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Student Activity Sheet #2

8. Explain what it means when the albedo increase to 0.350 %? _____

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9. When you increased the albedo to 0.350, how was :

a. the amount of heat (R Wm^{-2}) coming from the Earth's surface affected?

_____

b. the surface temperature affected? _____

10. What does an increase in atmospheric absorptivity mean? _____

_____

11. What effect did it have on :

a. the amount of heat coming from the Earth's surface? _____

_____

b. the surface temperature? _____

_____

12. What does a lowering of the solar constant mean? _____

_____

13. What effect does a change in the solar constant have on the Earth's surface temperature?_____

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14. According to Mitchell's article, why does the movement of energy within the Earth system become more and more complex? _____

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15. Explain how feedback mechanisms work in this activity. _____

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