Climate Modeling
(Part A The Energy Balance Model)

The Environment and Disease Laboratory 2A
Fall 2002

Introduction

Recall that energy balance models view the climate of Earth in terms of its global energy balance. Over 70% of the energy that drives the climate is first absorbed at the surface. This energy is conducted to the atmosphere and, via heating of the surface, causes longwave radiation that is the basis for greenhouse warming. Thus, the proportion of energy that is reflected, the albedo, is an important factor when considering energy input to the global climate system.

In this lab you will use an implementation of the one-dimensional energy balance model created by McGuffie & Henderson-Sellers (1997). This model was originally created by Sellers and Budyko in 1969. The simulation you will use implements the balance equation:

(Shortwave in) = (Transport out) + (Longwave out)

As discussed in class, this is realized by the equation:

$$S(l) * (1 - a(l)) = K*(T(l) - T_{avg}) + (A + B*T(l))$$

in which

- l = the latitude
- S(l) = the mean annual radiation incident at latitude l
- a(l) = the albedo at latitude l
- T(l) = the surface temperature at latitude l
- T_{avg} = the mean global surface temperature
- A and B govern longwave radiation loss and are constant
- K = the transport coefficient determining how energy leaves/enters a latitude zone

In the model these and other parameters are given reasonable default values. The albedo is set to the albedo of ice (0.62) if the temperature falls below a critical value T_c (initially set to -10^{o}C); otherwise, the albedo of the underlying land in that zone is used.

Model Algorithm

The model seeks to find an equilibrium state according to the following algorithm.

1. Initialize the zonal temperatures
2. Do the following until the different latitude temperatures, T(l), no longer change
   a. Calculate the albedo of each zone
   b. Calculate the mean temperature of the system
   c. Determine the new temperature at each latitude, via the above equation.

The Simulator

The simulator has two primary panels. The left panel lists the various global constants (e.g., Solar Fraction). The right panel lists the 9 different latitudes that are resolved. Note that only one hemisphere is modelled. The right panel also indicates whether the model has converged as well as the status of the simulation. **Important: You can modify parameters that have blue backgrounds. The fields with red backgrounds cannot be modified.**

- The **Compute** Button causes the simulator to attempt to reach equilibrium. It will iterate no more than the number of iterations listed in the Loop field. Important: If you press compute and the model fails to converge, the results are meaningless. Check your parameters, since you probably made a mistake while typing. Each run begins with the temperatures and albedos left from the previous run.
- The **Reset** Button resets the simulator to initial conditions much like those that exist today.
- You can modify the albedos of different latitudes by entering a new number (between 0 and 1) into any of the nine blue Surface Albedo fields. You must then hit Calculate to cause the model to find a new equilibrium.

Directions

1. Familiarize yourself with all parameters on the screen. You should be able to pick out where each appears in the equations for the model that we derived in class.

   The model is said to converge when the average of the individual latitude temperatures equals the global average temperature. See if you can find a numerical value for some parameter that causes convergence to fail when the model loops 50 times and attempts to achieve an accuracy of .001. Write the parameter name and value below. Explain why you think this parameter causes convergence to fail.

____
____
____
____
____
____

2. Raise the albedo of the three latitude regions nearest the equator to 0.3 to simulate what *might* happen with increased cloud cover. What happens to the global temperature? Are other latitudes affected? Why?

____
____
____
____
____
____

3. Using the default values, determine how much the solar constant must decrease to *just* glaciate the Earth (permanent ice forms down to the equator). This will be that point where all of the Earth has a temperature below T_{crit}. Do you notice anything about nearby values of the solar constant?

____
____
____
____

4. Reset the model to its initial state. How much does the solar fraction need to change before the entire permanent ice pack melts? If the initial state is a good model of the current climate, is the Earth nearer to an ice age or an "iceless" age?

____
____
____
____
____

5. Now, starting with a just glaciated Earth, try setting the solar fraction back to 1.0. You will find that the Earth return to its current state? Try to explain the reason(s) behind what you observe.

____
____
____
____
____

6. What happens if you raise the solar fraction higher, in an attempt to regain the current state of the Earth? What combination of changes to the solar fraction will move the Earth from an ice age back to its present state? What does this indicate about the climate equilibrium that the Earth currently enjoys?

7. Examine the model's sensitivity to each of the global parameters (A, B, K, T_c, A_{ice} when that parameter is varied independently while the others are held constant at their initial values. This is known as sensitivity analysis; it helps determine which factors influence the climate most strongly. You should use some percent of each parameter's default value and indicate a standard method for measuring sensitivity quantitatively. Describe the sensitivity measure that you chose. Order the parameters according to how much they affect the outcome. Try to refer your findings back to the real model.