

1 Energy Balance Model Practical

1.1 Introduction

In this practical, you will be provided with a program which implements the simple zonal energy balance model discussed in the lectures and described by McGuffie and Henderson-Sellers. Having run it once and observed that the temperature and the various radiances behave as you have learned, you may then experiment with it by making the Sun more or less powerful, changing the albedo, controlling the meridional transport and so forth.

The model itself is sufficiently simple that you could code it up from the course notes in an afternoon. Most state of the art climate models are too complex for one person to know how every part of them works, and the job of the working climate scientist is often to use a model which he or she did not write. In this respect at least, the exercise is quite realistic.

1.2 Zonal energy balance models: revision

It is observed that although the Earth as a whole is in radiative balance, with incoming (solar) and outgoing (longwave) fluxes, F_{in} and F_{out} , being equal. This is not true for an individual latitude band. Low latitudes receive more energy from the sun than they radiate, while high latitudes radiate more than they receive. So the climate system must move energy from equator to poles. We can make a simple model of this by assuming that the energy balance for a zone at latitude θ has three terms:

$$F_{\text{in}}(\theta) + Q(\theta) = F_{\text{out}}(\theta)$$

with Q representing the energy flowing into this zone from its neighbours.

We parameterise these three terms as functions of the surface temperature T as follows:

- $F_{\text{in}} = S(\theta)(1 - \alpha(T))$ where $S(\theta)$ can be calculated from geometry. The albedo, $\alpha(T)$ might be set to 0.6 for T well below freezing and 0.3 for T well above freezing, with a more or less abrupt transition between the two regimes.
- The linear parameterisation $F_{\text{out}} = A + BT$ is often used here. The underlying physics is approximately a 4th power law (Stefan's law) for a temperature considerably less than the surface temperature. A and B are usually obtained by fitting a straight line to measurements
- $Q = K(\bar{T} - T(\theta))$ where \bar{T} is the global mean temperature. So a zone is warmed if it is colder than the global mean and warmed if it is cooler than the global mean.

The energy balance equation is therefore:

$$S(\theta)(1 - \alpha(T(\theta))) + K(\bar{T} - T(\theta)) = A + BT(\theta)$$

We can re-arrange this as follows:

$$T(\theta) = \frac{S(\theta)(1 - \alpha) + K\bar{T} - A}{K + B}$$

and solve this iteratively as indicated in Figure 1.

1.3 Getting started

1.3.1 Logging on and getting the model: What should happen

You need the machine to be running Linux, not Windows. If it is currently running Windows, then re-boot it into Linux.¹ Log in with your user name and password² You will need to download the model code. Do this by typing this URL into your web browser

¹Do Ctrl-Alt-Del then press the Options button, then the Shutdown button, then choose “Restart” from the list and press the OK button. Watch the machine as it re-starts. When it reaches the gray GRUB boot screen, choose LCFG quickly. If you are not quick, the machine will re-boot into Windows.

²If your EASE password is different from your Windows password then you want the WINDOWS password.

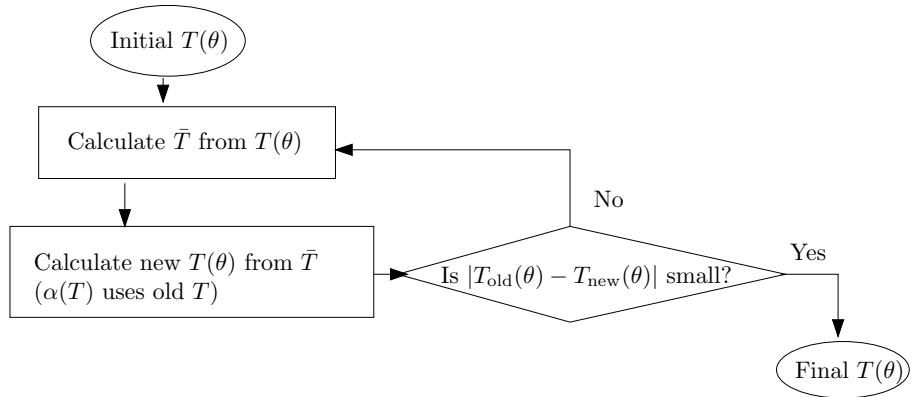


Figure 1: Flow diagram showing how temperature is calculated.

http://xweb.geos.ed.ac.uk/~hcp/poc_lab

... and then right-clicking on the relevant link. Choose “Save Link as” and then select your home directory as the place to save the file. You should end up with a file called tk_hsmcg.R. The model needs to be run from a terminal window: start this using the button in the bar at the top of the screen.

1.3.2 Logging on and getting the model: The back-up plan

If everything in section 1.3.1 has worked, then ignore this section and go directly to section 1.3.3. These instructions are just here in case you can not log in to the LCFG machines. Log in to one of the PCs using your usual Windows username and password. (You may have to hit the power button to wake the machine up.) The model is run on a Linux machine called fleet. To connect to this, use the Windows menu, choosing the item:

All Programs→School Applications→Science and Engineering→Geosciences→Connect to→Connect to Fleet

You will be asked for your username and password again. (This time, you want your EASE (SMS) password if it is different from your Windows password.) Once you have logged in you will be presented with an xterm window containing a prompt :~bash-3.00\$ at which you can type commands. Obtain a copy of the model by typing:

`cp ~hcp/wrk/poc/practs/ebm/tk_hsmcg.R .`

Don't miss out the space and the dot at the end of that command.

1.3.3 Getting started with the model

The model is written in a language called R. Start R up by typing R at the prompt in your terminal window and pressing return. You will see R's startup message and its prompt >. Start up the model itself by typing

`source("tk_hsmcg.R")`

at the R prompt. The program should present you with two windows. One of these contains graphs of various model quantities as a function of latitude. The top graph shows surface temperature in black. The red line is the initial value of the temperature and the grey dotted lines show the results at various iterations on the way to the final answer. The central graph shows albedo. The bottom graph shows the various fluxes: $S(\theta)$ in red, $(1 - \alpha)S(\theta)$ in green, F_{out} in black and $(1 - \alpha)S(\theta) - F_{\text{out}} = -Q(\theta)$ in blue.

The other window contains various buttons and sliders to control the model. You can experiment with the model by moving the sliders about and then pressing the button labelled **Run EBM**. You can always set the controls back to their starting positions by pressing the button labelled **Default Settings**.

1.4 Experiments to try

These are suggestions – feel free to alter any of the model’s parameters.

1.4.1 Solar Constant

Alter the solar constant from 1370.0 to 1570.0; Where would you invest in real estate if the sun increased its output in this way? What happened to the polar ice cap? What happens if you reduce the solar constant from its current value? In particular, what happens in the vicinity of $S_0 = 1150 \text{ Wm}^{-2}$

What is $\frac{d\bar{T}}{dS_0}$ of the model³ with

- (a) the current solar constant
- (b) a solar constant of 1570 Wm^{-2}
- (c) a solar constant of 1150 Wm^{-2} and
- (d) a solar constant of 1050 Wm^{-2} .

You can estimate $\frac{d\bar{T}}{dS_0}$ by altering S_0 by a few Kelvin and seeing how much \bar{T} (displayed at the top of the control window) changes. Why is (c) so different from the other cases?

1.5 The starting point

So far, the model has always used the same values as its starting point. Press the **Default Settings** button and then press the button marked **start from previous run** and re-run. You will notice that the initial and final temperatures are the same. Decrease the solar constant in steps of 20 until it reaches 1110 Wm^{-2} , noting the temperature at each step. Now increase the solar constant again. How far do you have to increase it before the world reverts to a familiar state?

1.5.1 Meridional flux

Set the solar constant back to 1370 Wm^{-2} by pressing the **Default Settings** button, and try changing the transport parameter K with the slider labelled **Meridional Transport**. First, try setting it to zero. What effect do you think this will have on the Outgoing Longwave Radiation (OLR)?

Were you right?

³ $\frac{d\bar{T}}{dS_0}$ is the climate sensitivity, apart from a factor of $(1 - \alpha)/4$.

Next, try making it as large as the program allows. What do you think will happen?

Were you right?

1.6 Albedo

How much difference does it make if the unfrozen part of the world has an albedo of 0.4 instead of 0.3?

What happens if ice is perfectly white?

What happens if ice is *darker* than the unfrozen surface? Is it realistic?

1.7 Finishing up

If you want to leave R at any point, type `q()` at the R prompt. Please log off the PCs before you leave.

1.8 Taking the model home

The model is on the course web site. There is only one file: `tk_hsmcg.R`. To run it, you need R, which you can obtain from <http://www.r-project.org> for most modern operating systems: MacOS X, Microsoft Windows (95, 98, Me, 2000, XP), Linux or any modern Unix.