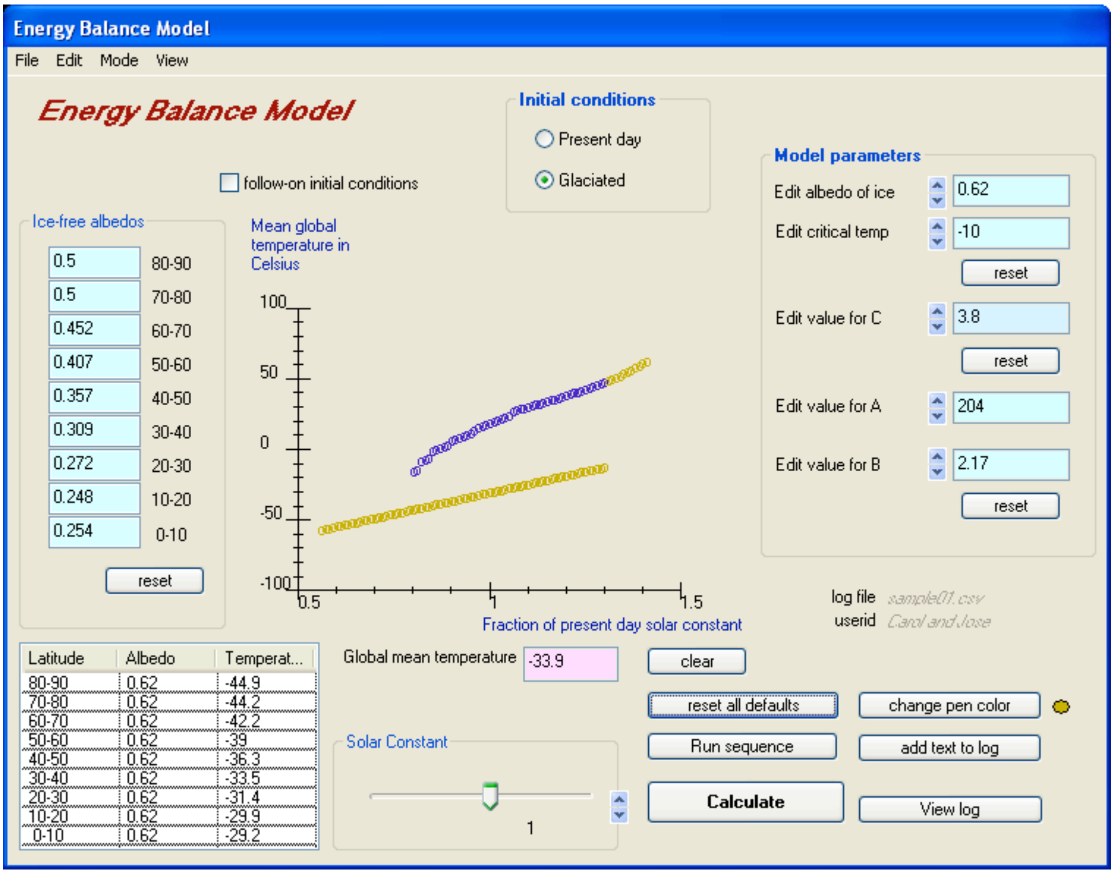


EBM

USER MANUAL AND EXERCISES

Version information

Date	
4 Sept 05	Initial draft
5 Sept 05	Beta draft for circulation with version 2.0 of EBM. Version 2.0 has log files which can be saved for later analysis in a spreadsheet. Used at UTS.
9 June 2006	Version 2.1 of the EBM includes a fix for a couple of minor bugs and a fix for a bug which made the model abend due to an address bounds exception. Included an untested Linux version in the distribution for the first time. The manual was updated only to change the 2.0 to 2.1.

EBM v2.1 Manual

1. Introduction

This manual contains information about Version 2 of the Energy Balance Model from ‘A Climate Modelling Primer’. The manual contains a description of the fundamentals of energy balance models (Section 2) and describes how to get answers from this very simple implementation of a climate model (Section 3). Section 4 includes some simple exercises that could be used in a class or for self-directed study.

2. Energy Balance Climate Models

This type of climate model is a useful teaching/learning tool. The program was originally written for undergraduate use at the University of Liverpool in the early 1980s. This version has been updated to allow for increases in the performance of personal computers and a few new features have been added that make integration into a broader learning program more feasible.

The formulation of the EBM here has been kept as simple as possible. The equations are those described in Section 3.2 of ‘A Climate Modelling Primer’. The albedo parameterization is a simple 'on-off' step function based on a specified temperature threshold. The emitted longwave radiation is a linear function of the zonal surface temperature and the transport term is a simple diffusive term dependent on the difference between the zonal temperature and the mean global temperature. The following sections contain a brief summary of the model presented in Figure 3.2 and suggest some exercises which demonstrate the model's behaviour.

2.1 Quick Description of the EBM

The model is governed by the equation originally devised by both Sellers and Budyko in 1969

(Shortwave in) = (Transport out)+ (Longwave out)   (3.18)

which is formulated as

$$S(\phi)\{1-\alpha(\phi)\} = K\{T(\phi)-\overline{T}\} + \{A+BT(\phi)\} \qquad (3.19)$$

where

K   the transport coefficient (here set equal to 3.80 W m^{-2} °C^{-1}),

T(φ)   the surface temperature at latitude ϕ,

$\bar{T}$ the mean global surface temperature,

A and *B* are constants governing the longwave radiation loss (here taking values $A = 204.0$ W m^{-2} and $B = 2.17$ W m^{-2} °C^{-1}),

$S(\phi)$ the mean annual radiation incident at a latitude ϕ,
$\alpha(\phi)$ the planetary albedo at latitude ϕ.

Note that if the surface temperature at ϕ is less than -10°C the albedo is set to 0.62. The solar constant in the model is taken as 1370 Wm^{-2}.

The EBM is designed to be used to examine the sensitivity of the predicted equilibrium climate to changes in the solar constant. If the default values for the variables *A*, *B*, *K* and the albedo formulation are selected, an equilibrium climate which is quite close to the present-day situation is predicted for a fraction = 1 of the solar constant. This equilibrium climate is given when the model starts.

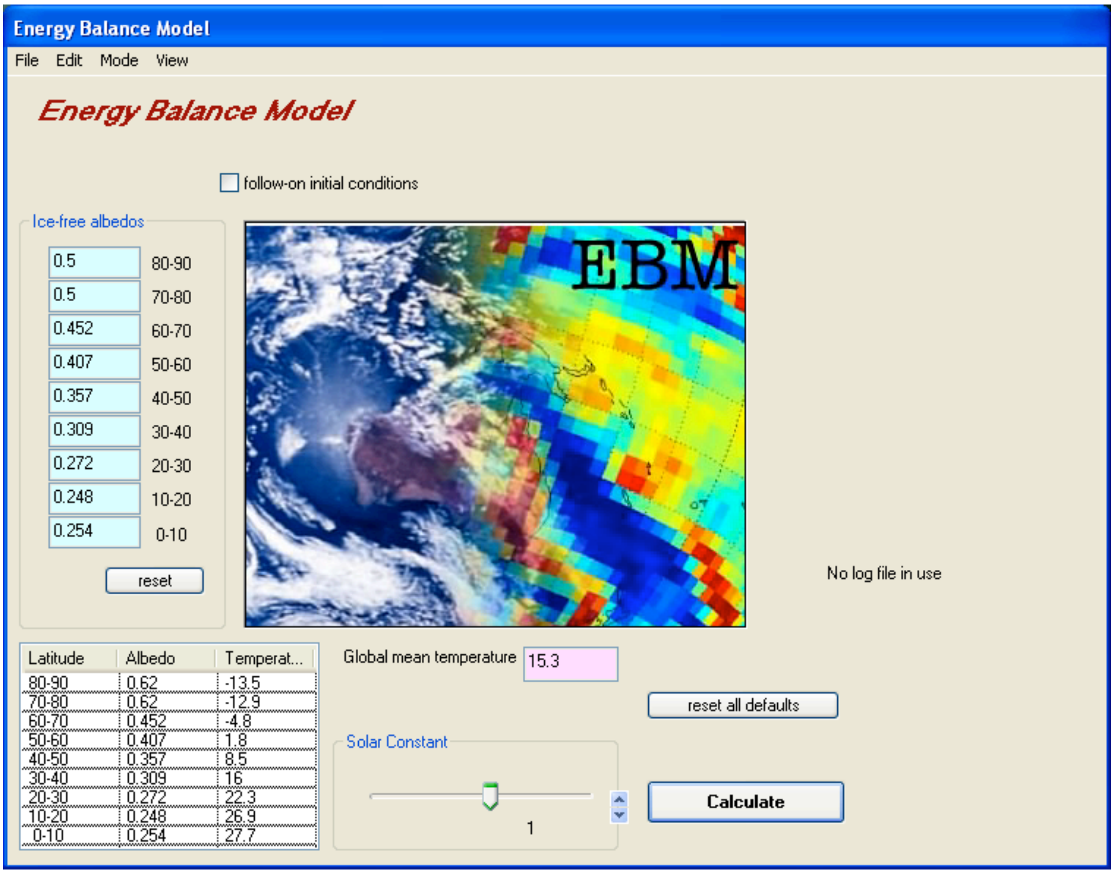
Once this equilibrium value for an unchanged solar constant has been seen, the user can modify the fraction of the solar constant prescribed and note the changes in the predicted climate. More importantly, the EBM permits the user to alter the albedo formulation, the latitudinal transport and the parameters in the infrared radiation term and examine the sensitivity of the modified model. The EBM is presented here in a hemispheric form.

In the program, an equilibrium solution is achieved by iterating the calculation of each zonal T_i of equation (3.13). A maximum of 50 iterations is allowed, and since convergence is usually achieved after only two or three iterations, more than 50 iterations indicates that the calculation has failed. The snow-free albedo of the planet has been coded as latitude dependent. Remember that this is the snow-free planetary albedo. We include the effects of clouds in these numbers.

2.2 Starting the EBM

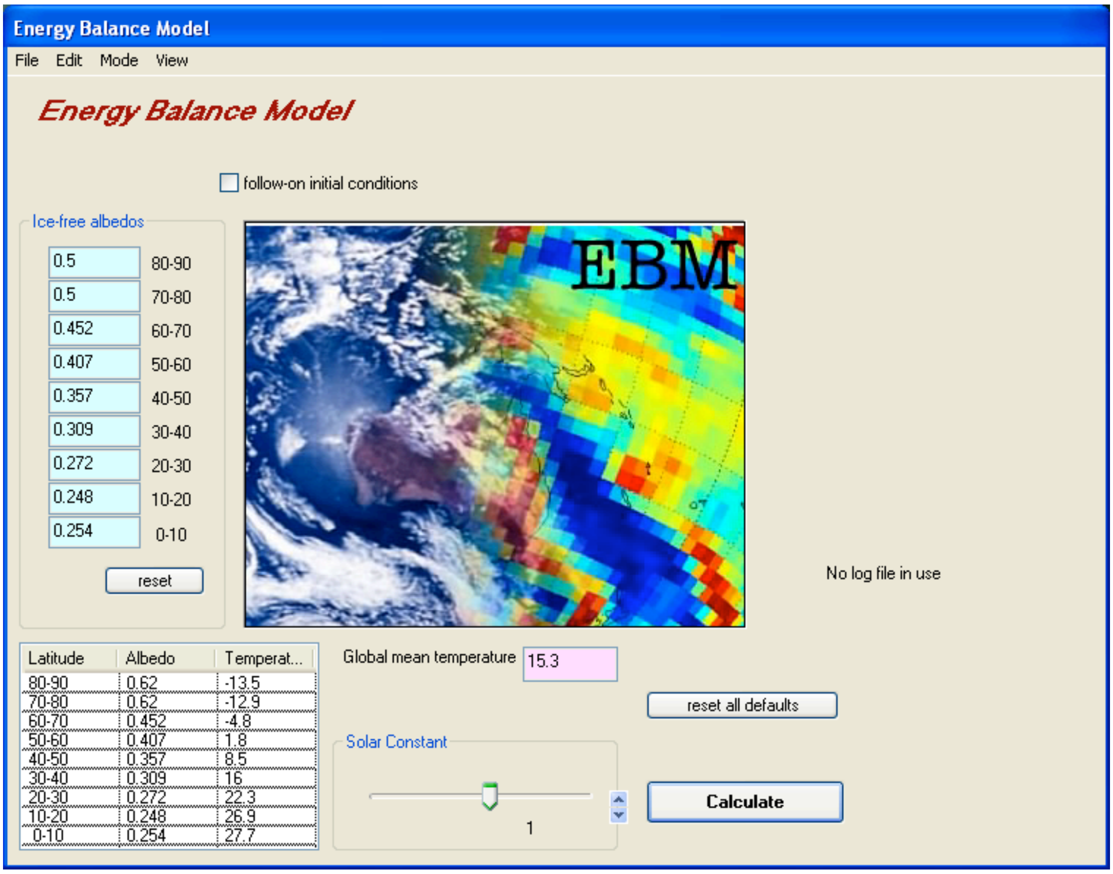
The model is currently made for Windows XP/2000, and for Macintosh OSX. Linux builds and Macintosh Classic versions are included in the distribution, but I have no way to test these versions, so who knows how well they work. The images in this document are for Windows-based computers, but the layout should be the same for all systems.

To start the model, double-click on the EBM2.0.exe file. The EBM screen should appears as below.



3. EBM Functionality

3.1 Basics



The EBM is a very simple application. A few simple things are visible when you first open the application.

(i) The value for the solar constant can be changed using the slider or (more finely) by the small arrows on the right of the slider.

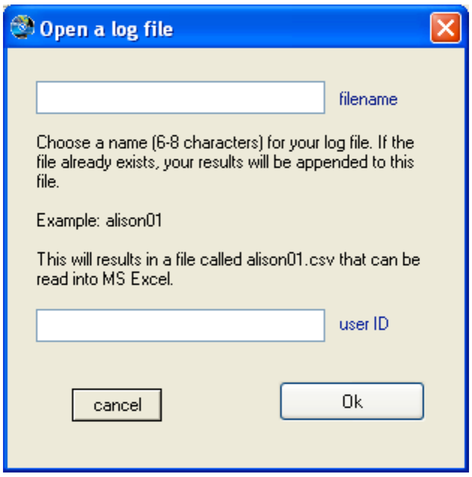
(ii) When the calculate button is pressed, the model displays the resulting global mean temperature in the text field and updates the zonal climates accordingly.

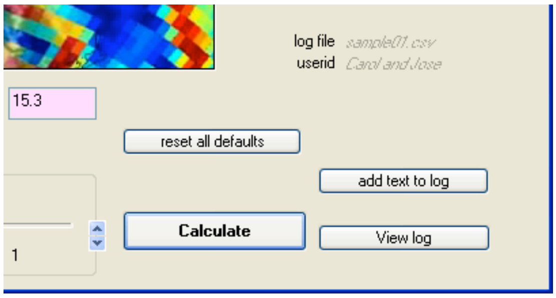
(iii) Default values for parameters and for the solar constant can be reset using the ‘reset all defaults’ button.

Further aspects of the model can be changed as the various modes of the model are activated as described below.

3.2 Logbook

The EBM can save results to a log file for later analysis and plotting in MS Excel or similar package. To open a log file, choose 'open a log file' from the file menu and complete the fields in the dialog box below.



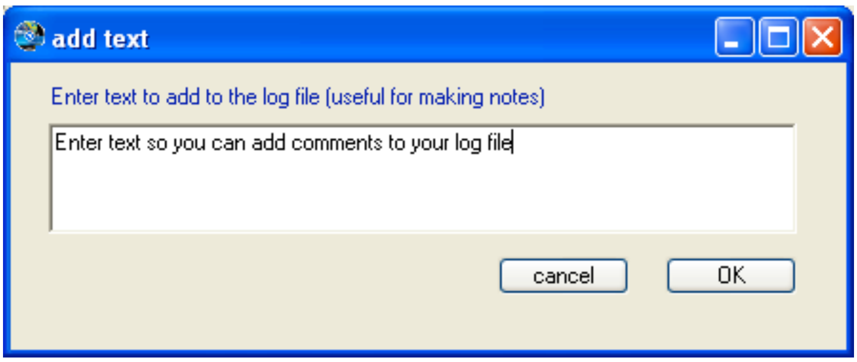


Choose a filename for your file (it will be saved as a .csv file) and add an optional user ID to assist in identifying the file. The filename will be displayed in the main window when the log file is active.

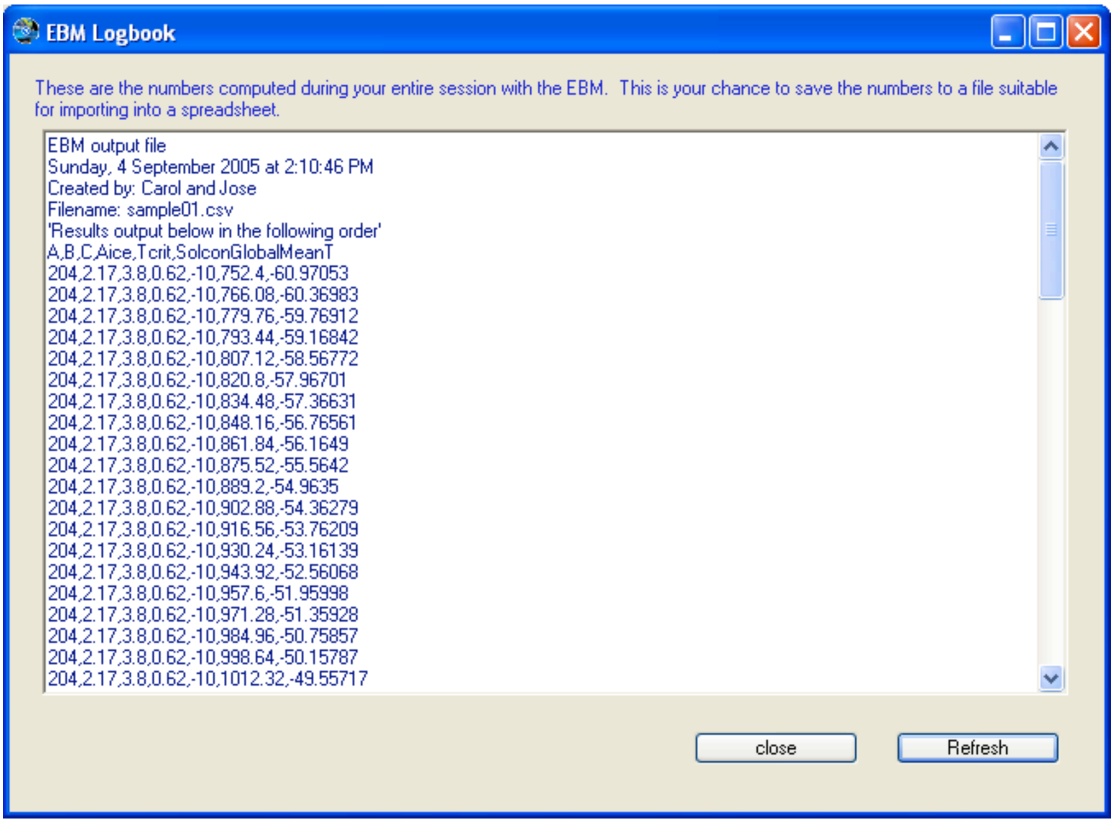
The log file name and user ID are displayed as show above to remind you where to find your results.

The log file cannot be turned off until the program is closed (by selecting quit from the file menu (or program menu for Macintosh users).

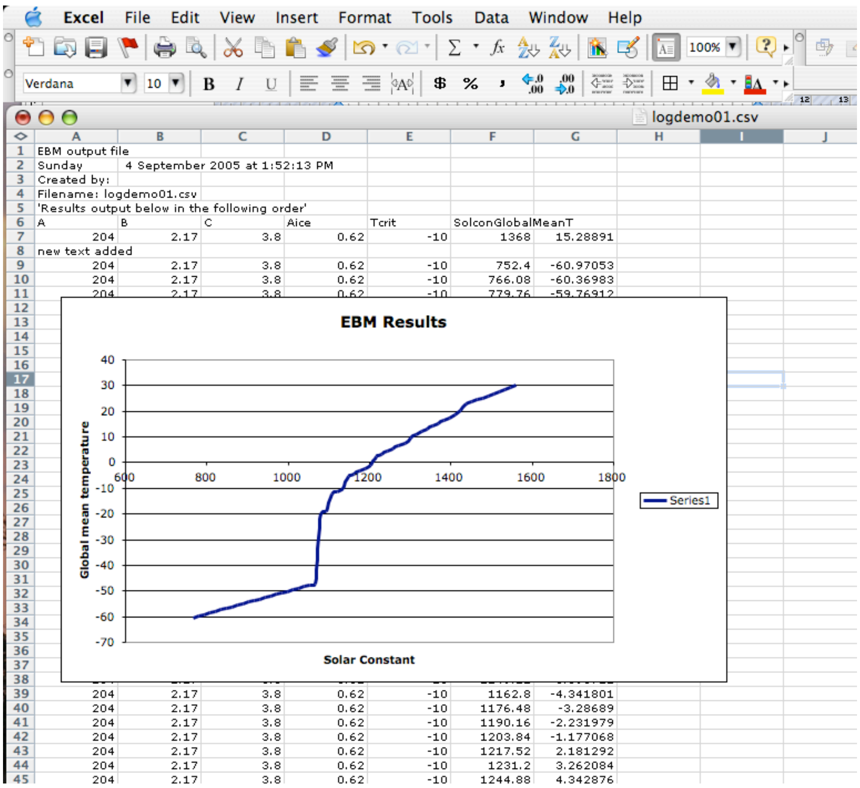
The figure below shows the logbook window after a few calculations have been made using the sequence button. You can use the 'add text to log' button to add comments to your log file.



The log file can be checked by clicking the 'view log file' button. A sample view of a typical log file is shown below. This can be readily imported into a spreadsheet as illustrated.

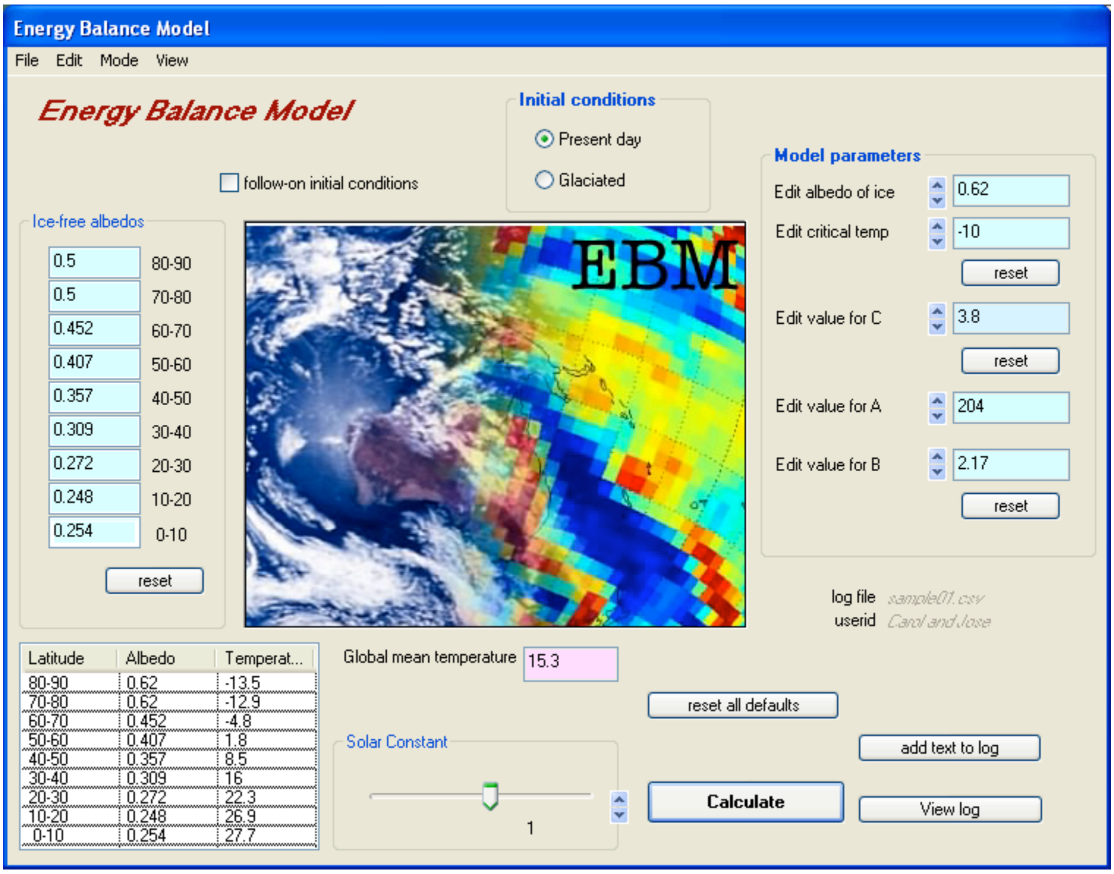


Use the refresh button to update the screen if need be. The log file cannot be stopped, but you can start a new log file at any time, effectively closing off the first one. If you use the same name, the file will be overwritten.



3.3 Expert mode

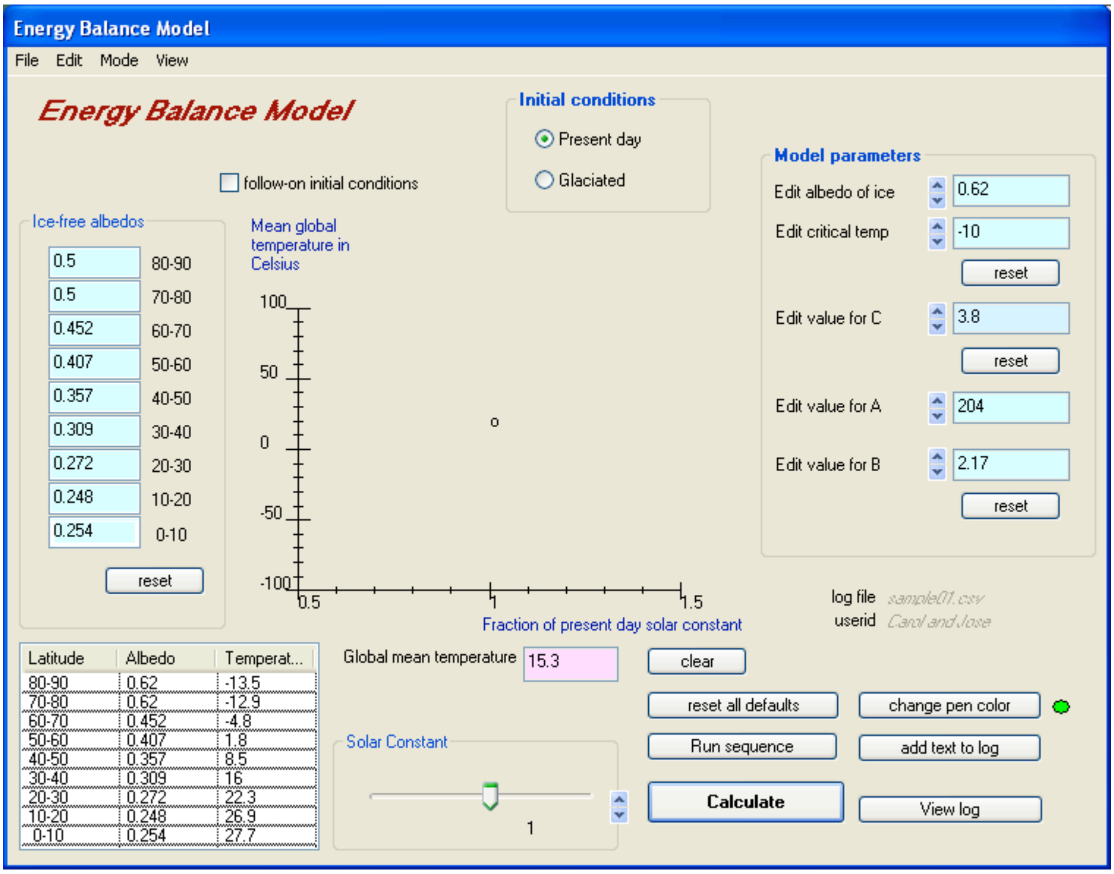
When you are more familiar with the model, an 'expert' mode allows changes to be made to all of the model parameters. This expert mode can be enabled by selecting 'expert' from the file menu. Additional edit fields appear on the right and the albedo fields on the left become editable. Parameters can only be changed within a range of plausible values. If you choose a value that is either implausible or outside a predefined range, the model will alert you with a small red oval beside the problem value and reset it to the default value. Unreasonable values can cause the model computations to become unstable, hence the range of values has been limited.



3.4 Graphics mode

The colour image can be replaced by a graph that plots the mean global temperature as a function of solar constant as values are computed by the user. Select 'graphics' in the mode menu to activate the graphics canvas. Users can change the colour of the 'pen' (selected at random each click) and can clear the canvas by pressing the 'clear' button. When graphics mode is activated, the screen looks like the one presented below.

At the moment, there is not a way to copy the graphics from the canvas into another document. If you wish to save the picture created, use ALT+PRTSCRN on Windows machines and the ***Grab*** program on Macs.

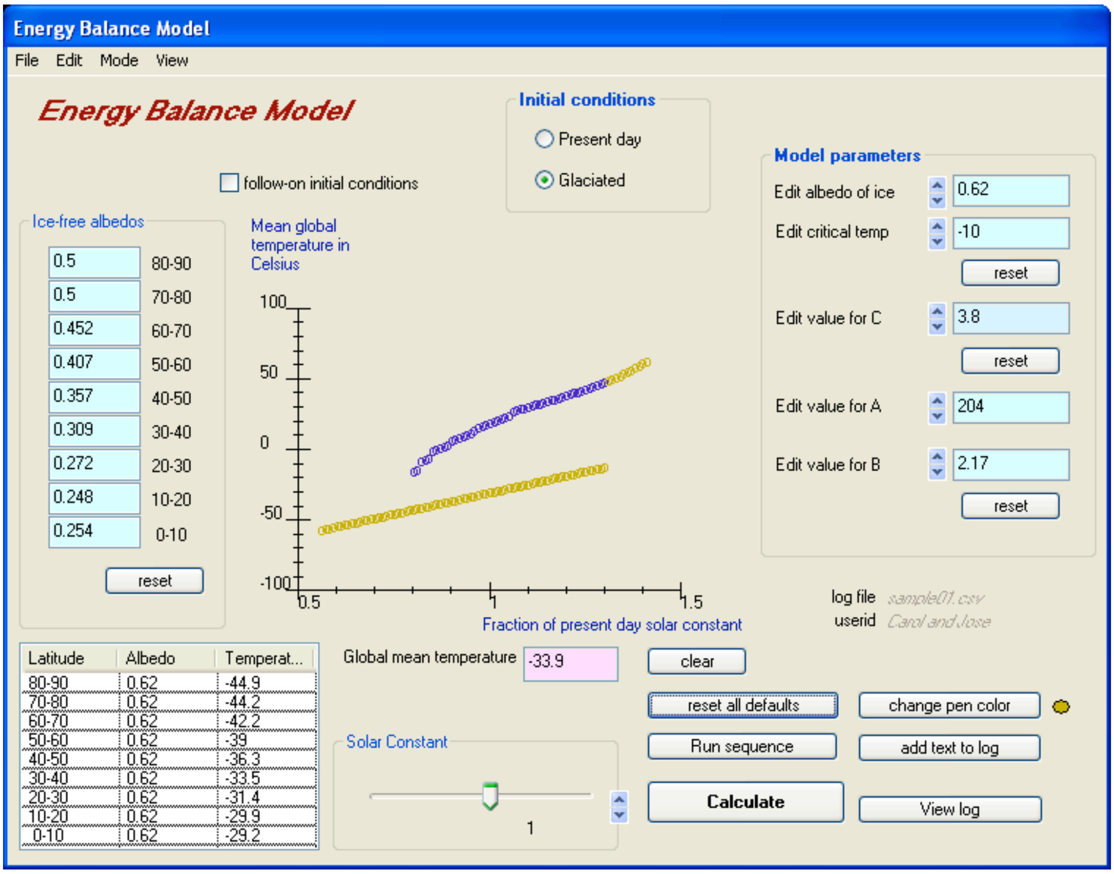


0.5	80-90
0.5	70-80
0.452	60-70
0.407	50-60
0.357	40-50
0.309	30-40
0.272	20-30
0.248	10-20
0.254	0-10

Latitude	Albedo	Temperat...
80-90	0.62	-13.5
70-80	0.62	-12.9
60-70	0.452	-4.8
50-60	0.407	1.8
40-50	0.357	8.5
30-40	0.309	16
20-30	0.272	22.3
10-20	0.248	26.9
0-10	0.254	27.7

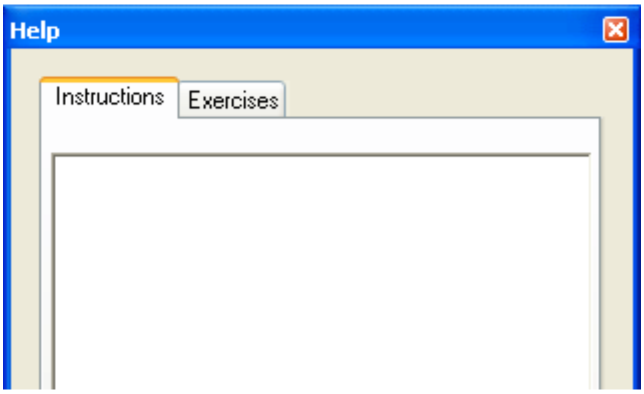
3.5 Sequence mode

When graphics mode is selected, you can also enable and use the sequence mode. Sequence mode runs a set of simulations for a range of values of solar constant and can be useful when experimenting with different parameter values.



3.6 Help/Instructions dialog

The instructions box does not currently function in Windows. In future versions it may contain customisable instructions and exercises.



4. EBM Exercises

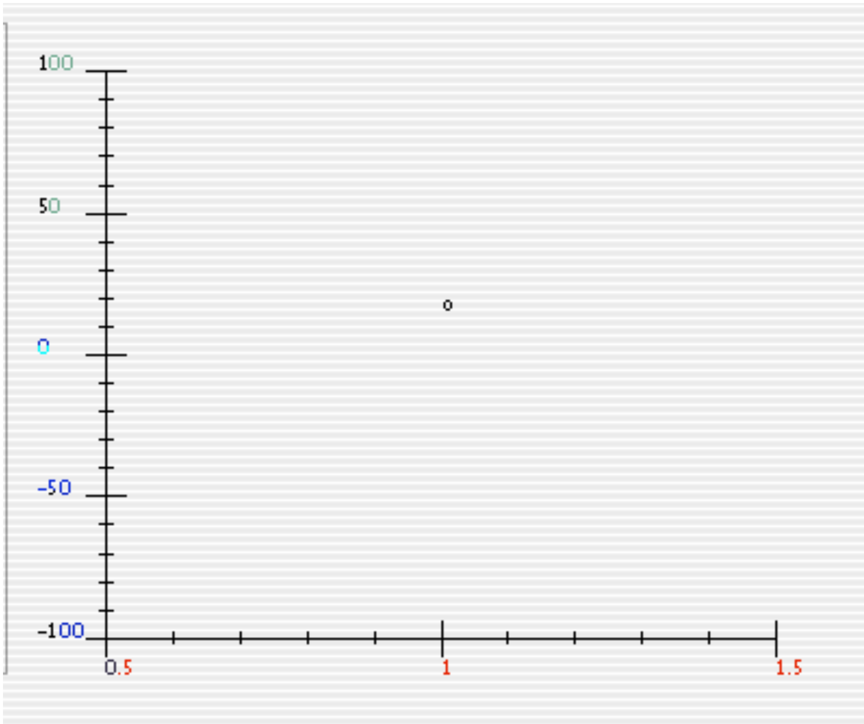
Take some time to work through the exercises below. They are useful examples of the types of climate simulation experiments that can be undertaken.

4.1 Snowball Earth

Exercise 1.

(a) Using the default values of set in the program, determine what decrease in the solar constant is required just to glaciate the Earth completely. Adjust the solar constant using the slider and press the 'calculate' button. At this stage, just observe the 'ice' indicated by the albedo value of 0.62 in the table.

(b) Now make the model a little more realistic by making the model use the results from its simulation as initial conditions for the next run. Once the ice covers the Earth, how much increase in solar constant is required to break free of this 'snowball Earth' state?


100
50
0
-50
-100
0.5
1
1.5

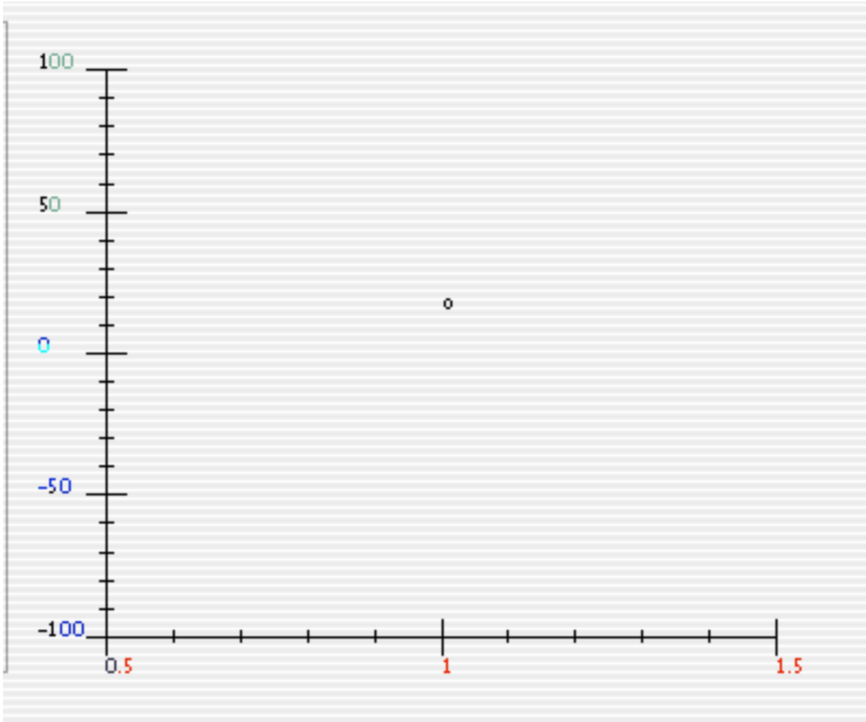
4.2 Atmospheric and Oceanic transport

You will want to switch to graphics mode and use the 'sequence' feature in this exercise.

Exercise 2.

(a) Various authors have suggested different values for the transport coefficient, *K (C in the model used here)*. For instance, Budyko (1969) originally used *K* = 3.81 W m^{-2} °C^{-1} and Warren and Schneider (I979) used *K* = 3.74 W m^{-2} °C^{-1}. How does changing the value of C affect the model climate and climate sensitivity?

(b) Investigate the climate that results when using very small or very large values of *K*. How sensitive are these different climates to changes in the solar constant? Try and 'predict' how you think the model will behave before you perform the experiment.


100
50
0
-50
-100
0.5
1
1.5

4.3 Further Exercises

This simple model can be manipulated further to simulate changes caused by continental configuration and in vegetation snow masking and cloud cover. Try these exercises.

Exercise 3.

(a) Observations show that land will be totally snow-covered during winter for an annual mean surface temperature of 0°C, and oceans totally ice-covered all year for a temperature of about -13°C. The model specifies a change from land/sea to snow/ice at -10°C appropriate for a land distribution similar to today's. Alter this 'critical' temperature and investigate the change in the climate and the climatic sensitivity around present day solar constant to changing the solar radiation input.

(b) The albedo over snow-covered areas can vary within the limits of 0.5–0.8 depending on vegetation type, cloud cover and snow/ice condition. Investigate the sensitivity of the simulated climate and climate sensitivity to changing the snow/ice albedo.

Exercise 4.

(a) There have been many suggestions for the values of the constants *A* and *B* determining the longwave emission from the planet — some have been dependent on cloud amount. Budyko (1969) originally used A = 202 W m^{-2} and B = 1.45 W m^{-2} $°C^{-1}$. Cess (1976) suggested A = 212 W m^{-2} and B = 1.6 W m^{-2} $°C^{-1}$. How do these different constants influence the climate and its sensitivity?

(b) Holding *A* constant, just vary *B* and investigate the effect on the climate. What does a variation of *B* correspond to physically?