Climate Dynamics Class Assignment
Energy Balance Models

Due: March 1 2011.
Computer: woodend
User Id: students
Password: Given in class
Files: Download from the links in the model notes.
Execute the *.m files at the matlab prompt by dropping the .m ending.
Questions 3 and 4 are numerical experiments so presentation
of (numerical) results either in a tabular or graphical form
is mandatory

1. (Theory) In the Lecture the longwave radiation formula (Stefan Boltzmann law) was linearized about a zero Celsius surface temperature so that

$$Q_{lw} = A + BT \tag{1}$$

where A and B are constants and T is the temperature in degrees Celsius. It was then argued that the greenhouse effect could be incorporated in an energy balance model by reducing (quite considerably) A and B. This was justified roughly in the Lecture 2 by using the one layer model of the previous module (i.e. that discussed in Lecture 1). In general one would expect optical depth (roughly e in the simple model) to increase as surface temperature increases since atmospheric moisture content increases as ocean temperature increases. Use a linear relationship for this increase and discuss what happens to A and B as a consequence of this water vapor feedback. Use the observational data provided in the Lecture to derive a value for the rate of increase of optical depth with temperature.

2. (Theory) In the zero dimensional energy balance model allow albedo to vary with temperature in the way discussed in the Lecture notes. As we saw in the Lecture this temperature dependency allows for the possibility of multiple equilibria in the climate system. Generalize this analysis to deal with the increase in optical depth with temperature using the formulation of the first question (not only does water vapour increase with temperature but it is also thought that carbon dioxide does something similar due to changes in global organic matter). What effect does this generalization have on the stability of the various equilibria?

3. (Numerical) In the zero dimensional EBM matlab gui switch on the advanced button as well as the albedo temperature dependency (switch off the blackbody button to enable the greenhouse effect). By choosing an appropriate set of parameters set the model up for three equilibria. Choose a range of initial conditions for temperature to verify the properties of all equilibria (including unstable ones!). Vary the greenhouse effect by

varying A and B. What effect does this have on the equilibria and their stability?

4. (Numerical) In the one dimensional EBM matlab script (one_dim_ebm.m) it can be shown that the Earth's climate system can undergo hysteresis i.e. the path from parameter setting X to Y is not the same as the path from Y to X. Study how this hysteresis loop varies as the angle of inclination of the Earth rotation axis varies. At present such variations are small ($22 - 24.5$ degrees) however in the distant future as the moon's distance increases they are likely to be much larger ($22 - 38$ degrees). This parameter is set in insolation_setup.m.

5. (Numerical - extra credit) In the one dimensional EBM, recode to allow for variations in A and B with temperature in the manner derived in the first question. Does this have any effect on the hysteresis loop? The changes need to be made in the solve_temp.m program.