ASSIGNMENT 4: ENERGY BALANCE MODEL USING STELLA

(10% of total mark)

Objective:

Illustrate the primary physical processes that dictate the Earth's temperature using STELLA. Create a model that accurately predicts the radiative equilibrium temperature that maintained the early Earth's energy balance.

Procedure:

1) The model structure should closely follow the one used in the previous EBM assignment using EXCEL. In particular, Eq. 3.1 from your respective reading should be used as the main building block:

$$(1-\alpha)S/4 = \sigma T^4 \quad (1)$$

   where α - planetary albedo, S - solar constant, σ - Stefan-Boltzman constant and T - effective temperature (see below for list of symbols and associated values).

2) In STELLA language the main stock will be "earth energy", E; the inflow "solar to earth" energy input (given by left-hand-side of Eq. 1); and outflow "earth to space" energy output (given by right-hand-side of Eq. 1). Eq. 1 assumes a zero-dimensional model, *i.e*. the Earth has no dimensions and mass. In this implementation of STELLA we include areas and weight, hence Eq. 1 has to be slightly modified: The energy fluxes in Eq. 1 are per total area and both, the r.h.s. and l.h.s. of Eq. 1 need to be multiplied by the respective surfaces (remember that the Earth receives energy over the area of a disc (circle) perpendicular to the incoming radiation but emits energy over the entire Earth surface).

3) The model computes energy, E, and not effective temperature, T, hence we need to connect the two. The relationship is:

$$T = E/C \quad (2)$$

   where C - heat capacity. Given that the surface of the Earth is primarily comprised of water, we can use the properties of water to calculate the Earth's heat capacity (making the assumption that the Earth is covered by a uniform layer of water of 1 m depth). C is calculated as follows:

$$C = \rho c_p V \quad (3)$$

4) Run the model over a period of 1 year (time increments of 0.01) with the initial value of the Earth energy stock set to 0.0. Make sure to calculate the energy input and output into and from the stock over the entire year! If in doubt, check units to examine the equations and results. Use built-in functions (*e.g.* for π) and scientific notation for very large or small numbers.

Questions:

1) Build and present model with a user-friendly interface [10 pts].

2) What value is predicted for the equilibrium temperature (briefly discuss). Present your result in graphical and tabular forms [2 pts].

3) It takes a relatively short time (fraction of one year) to reach an equilibrium temperature. This is a very short time compared to the age of the solar system. Is this short time a good or bad thing for planetary stability and the evolution of life on Earth [2 pts]?

4) Check the sensitivity to variation in the solar constant and present results in graphical form [2 pts].

5) Which variables are responsible for the inertia (time for the model to reach equilibrium) of the system. For example what would you change for the model to reach a slower equilibrium. Present your results in graphical form [4 pts].

6) Submit your model to the GE4212 workbin (Due date: Oct. 21, 23:59).

References/Sources:

McGuffie, K. and Henderson-Sellers, A., 1996: A Climate Modelling Primer (2nd ed.). Chapter 3.

Variables and units:

α - planetary albedo (0.3)
σ - Stefan-Boltzman constant (sigma) (5.678×10^{-8} J m^{-2} s^{-1} K^{-4})
S - solar constant (1370 J m^{-2} s^{-1} = W m^{-2})
J – Joule (measure of internal energy)
s – second
m - meter
K – Kelvin
R – radius of Earth (6371 km)
E – system energy (J)
T – effective temperature
C – heat capacity (J K^{-1})
V – volume (m^3)
c_p – specific heat of water (4218 J kg^{-1} K^{-1})
ρ – density of water (1000 kg m^{-3})