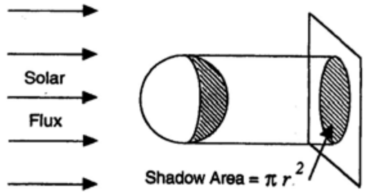
Explanation of the STELLA Energy Balance Models

The first subroutine on the left uses the value of the Earth's radius to compute both the **Earth's cross sectional area** and the **Earth's surface area**. The cross sectional area is needed to figure out how much SW solar energy flux is intercepted by the Earth's rotating sphere at any given time (sometimes called the "shadow area," see figure below). The Earth's surface area is needed to figure out how much LW (IR) radiation the Earth's surface is radiating outward to space in all directions.



Another subroutine is used to convert the **Solar Constant** and the **Stefan Boltzmann Constant** into **annual values**. Both constants are entered originally as values of energy in joules (J) per square meter (m^2) per second. To convert the constants to values for an entire year, they are each multiplied by the value "seconds-per-year" in this subroutine.

The next subroutine computes the **Heat Capacity of the Earth**, which determines how quickly the energy entering into the Earth Energy reservoir will heat up the surface. To keep the Energy Balance model simple, some very basic assumptions were made. One of these assumptions is that the surface of the Earth is *homogeneous.* Model #1 has been set up to compute the heat capacity of an Earth that is covered everywhere by one meter of water, i.e., a "one-meter swamp Earth." In the subroutine, the heat capacity calculation is based on the **specific heat** of water, the **density** of water and the **depth** of the water. (It is assumed that any energy absorbed by this swampy surface of the Earth will be "mixed" throughout the entire 1 meter depth of water.)

The final subroutine converts the temperature in Kelvin (K), which is normally used in Earth energy calculations like these, to degrees Celsius (C) and Fahrenheit (F) so that you can compare the values with temperature scales you are more familiar with.

Questions on MODEL #1: *(answer before you run the model)*

(1) What will happen if the solar "constant" were to change, but all other initial values stayed the same?

Assume the model is run initially with the current value of the solar constant. When compared with the results of this initial run, if the solar constant were to DECREASE (and albedo did not change), in the new model run:

Solar-to-Earth flux will: [increase / decrease / stay the same]
Energy in the Earth Energy stock will: [increase / decrease / stay the same]
Earth's surface temperature will: [increase / decrease / stay the same]
Surface-to-Space flux will: [increase / decrease / stay the same]

(2) What will happen if the albedo were to change, but other initial values stayed the same?

Assume the model is run initially with the Earth's current value of albedo. When compared with the results of this initial run, if albedo were to DECREASE (and the solar constant stayed the same):

Solar-to-Earth flux will: [increase / decrease / stay the same]
Energy in the Earth Energy stock will: [increase / decrease / stay the same]
Earth's surface temperature will: [increase / decrease / stay the same]
Surface-to-Space flux will: [increase / decrease / stay the same]

After you have run MODEL #1, click on the **GRAPH** icon to see what the model results look like graphically. Answer the following questions, based on the graph:

(3) How long does this model run for (in years)? _______

(4) How does the Solar-to-Earth flux vary over this time period? ____________________

(5) The Earth Energy and the Temperature lines plot more or less on top of each other. Write out the equation to show how Temperature is calculated by the model:

(6) If the Heat Capacity value does not vary with time, does the equation above explain why the Earth Energy and Temperature lines have the same shape? Briefly explain why or why not:

There is a lag in the response of the Surface-to-Space flux (blue line) **--** It begins to rise AFTER the Earth Energy/Temperature lines do, although eventually all three lines merge when they reach the same flat "equilibrium state" which indicates stability over time. *(You can see this lag effect "in action" by "dynamiting" the graph contents to clear away the plotted lines, "pinning" the graph open with the little stick-pin icon in the upper left of the graph, and running the model again.)*

(7) Why does the Surface-to-Space flux starts *after* the Earth Energy /Temperature lines begin to rise?

Finding Exact Ending Values for the Model Run Results

STELLA can provide ending values for any component of the model by using the "numeric display" bars. The model has already been set up with all the numeric display bars you will need. You can see them if you scroll down to the very bottom of the model with the cursor.

Initial Run Temperature Results

(8) What is the equilibrium temperature for the **Earth with NO atmosphere,** based on the Initial Run of the model? *(NOTE: the equilibrium temperature is the ending temperature after the Earth-Energy system has reached equilibrium).*

In Kelvin: _______ In ºC: _______ In ºF: _________

Does this agree with what you've learned the temperature of the Earth would be if there were no atmosphere and no natural greenhouse effect?

Now explore the model via new model runs by changing the converter variables, such as solar constant and albedo or other aspects of the model. You can check the temperature results in the numeric display bars.

Computing Values for a Comparison with MODEL #2

To **set the stage for running Mode #2,** you'll need to run the model one more time. Model #2 simulates the Earth Energy Balance WITH an atmosphere and runs the model for a "2 x CO2" scenario. To do this, MODEL #2 needs a longer time period to reach equilibrium, as well as a larger heat capacity. So that you can compare the results of MODEL #1 with the MODEL #2, you'll need to run MODEL #1 for 50 years and with a larger heat capacity. To do this, change the TIME SPECS to go from **0 to 50 years**, and change the **DT to 0.1** Then on the STELLA diagram, click on the **Depth** converter in the **Heat Capacity subroutine** and change the **water depth to 100 m**.

Explanation of MODEL #2 and Its Subroutines

Model #2 is an **"Earth Energy Balance Model WITH a One-Layer Atmosphere.** Note that instead of computing the Surface-to-Atmo flux directly from the Earth's surface temperature (as in Model #1), a "**Surface Radiation**" converter is added which together with a new "**GH Gas Factor**" determines how much terrestrial radiation gets absorbed into the Atmosphere Energy reservoir. The GH Gas factor can be viewed as a simple "atmospheric absorption coefficient" that determines what proportion of the terrestrial radiation gets absorbed in the atmosphere. A value of 1.000 would mean that ALL terrestrial radiation is absorbed by the atmosphere -- an environment that would be closer to what happens on the Planet Venus than anything we on Earth have experienced recently! A value of 0.000 would mean that *no* terrestrial radiation is absorbed, essentially eliminating the greenhouse effect. The GH Gas Factor that best represents today's concentration of greenhouse gases (both natural and anthropogenically enhanced) is ~ .766. If CO_2 were to double, this would increase the GH Gas Factor to ~.806. You'll run the model later to simulate a 2 x CO_2 world.

Model #2 also includes an "**Atmo Radiation**" converter that determines the rate of the two fluxes of radiation **out** of the Atmosphere Energy stock, i.e. how much IR energy the atmosphere radiates either downward to Earth's surface or upward and out to space. One thing that you will notice when the model computes the total Atmo Radiation (in J/yr) is that this also determines the flux rate (in J/yr) at which the atmosphere radiates both upward and downward. The atmosphere radiates equally upward and downward, so you will see the same flux rate of radiation showing up in different parts of the model.

Two **new subroutines** appear in the model: one to compute the **Heat Capacity of the Atmosphere** and one to convert the temperature of the atmosphere from Kelvin to Celsius to Fahrenheit.

Questions on MODEL#1 vs MODEL #2 *(answer before you run the model)*

When compared with the values of the No-Atmosphere Model (Model #1) the initial model run WITH an Atmosphere (Model #2) will show which of the following responses:

Solar-to-Earth flux will: [increase / decrease / stay the same]
The energy in the Earth Energy stock will: [increase / decrease / stay the same]
Earth's surface temperature will: [increase / decrease / stay the same]
Surface-to-Space flux will: [increase / decrease / stay the same]

The **Atmosphere Heat Capacity** computed by Model #2 will be [greater than / less than / the same as] the **Earth Heat Capacity** computed by Model #2.

The energy stored in the **Atmosphere Energy stock** computed by Model #2 will be: [greater than / less than / the same as] the energy stored in the **Earth Energy stock** computed by Model #2.

The **temperature of the atmosphere** computed by Model #2 will be: [greater than / less than / the same as] the **Earth's surface temperature** computed by Model #l. Is the atmospheric temperature value computed by the model reasonable **for a point about halfway through the troposphere**?

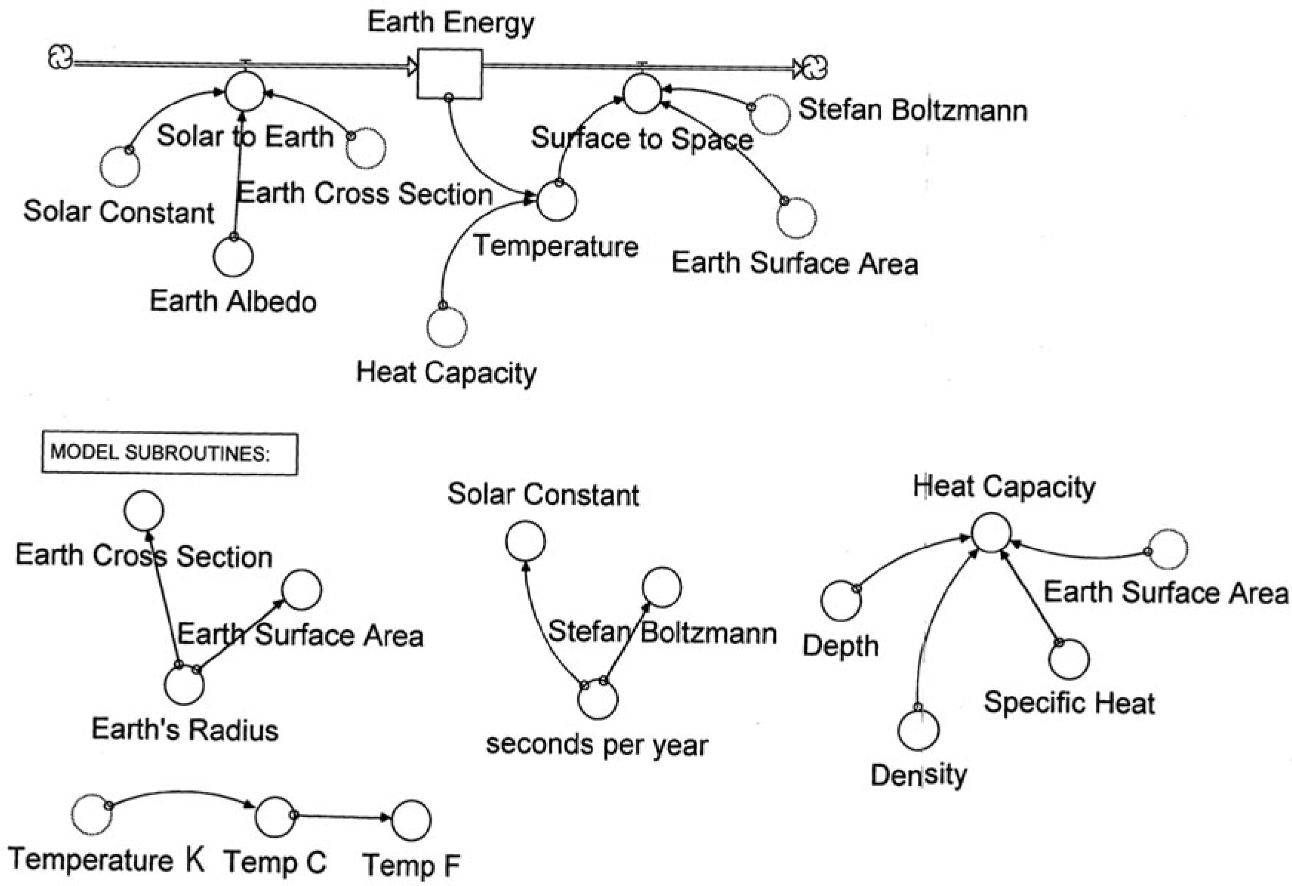
<u>Evaluating the Model Results</u>

After a doubling of CO_2 about **how much** does the model say the Earth's average equilibrium surface and atmospheric temperatures **WILL CHANGE**?

_______ K _______ ºC _______ ºF

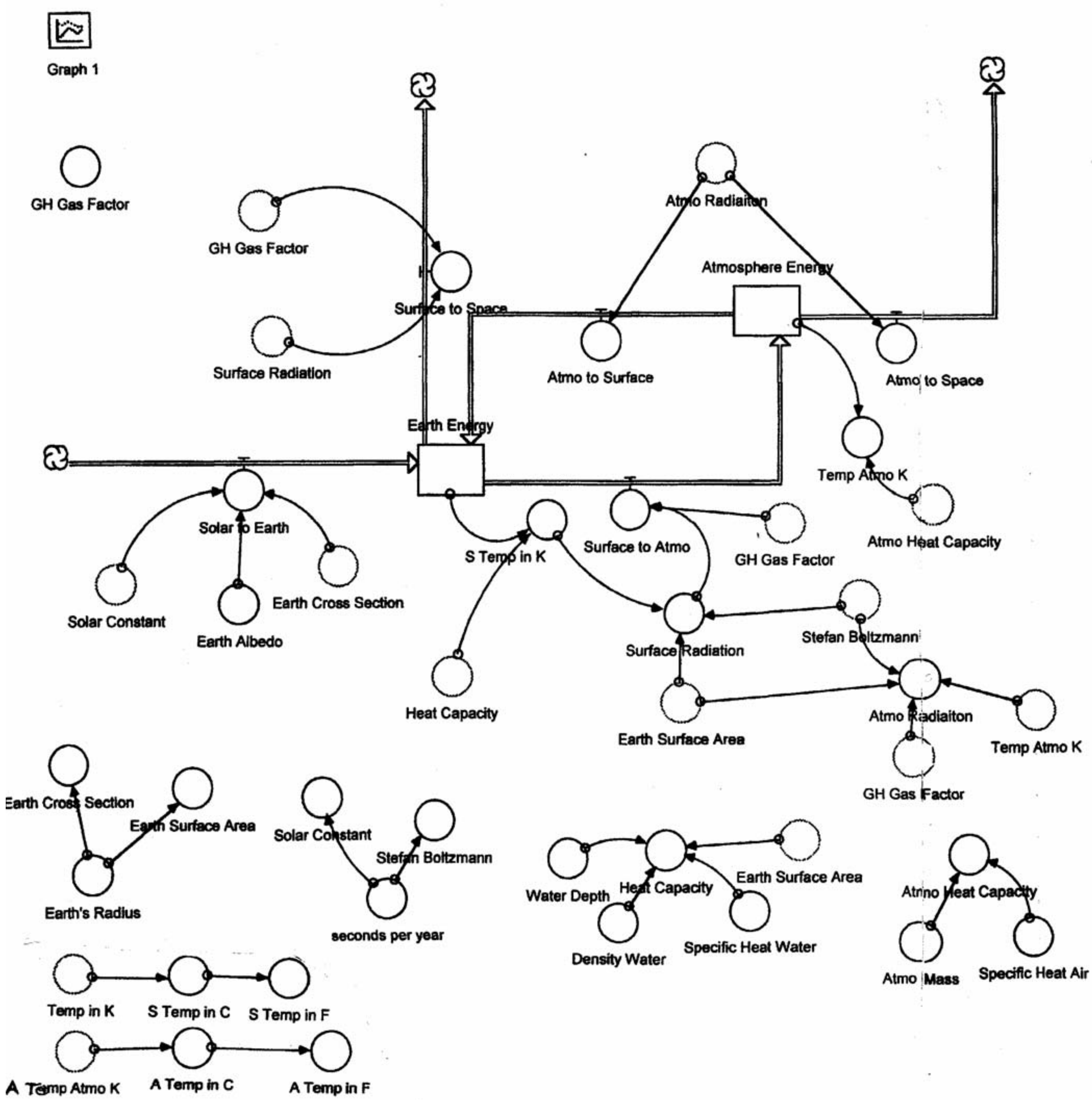
Is this within the range predicted by the 2001 Intergovernmental Panel on Climate Change (IPCC) based on one-dimensional models?

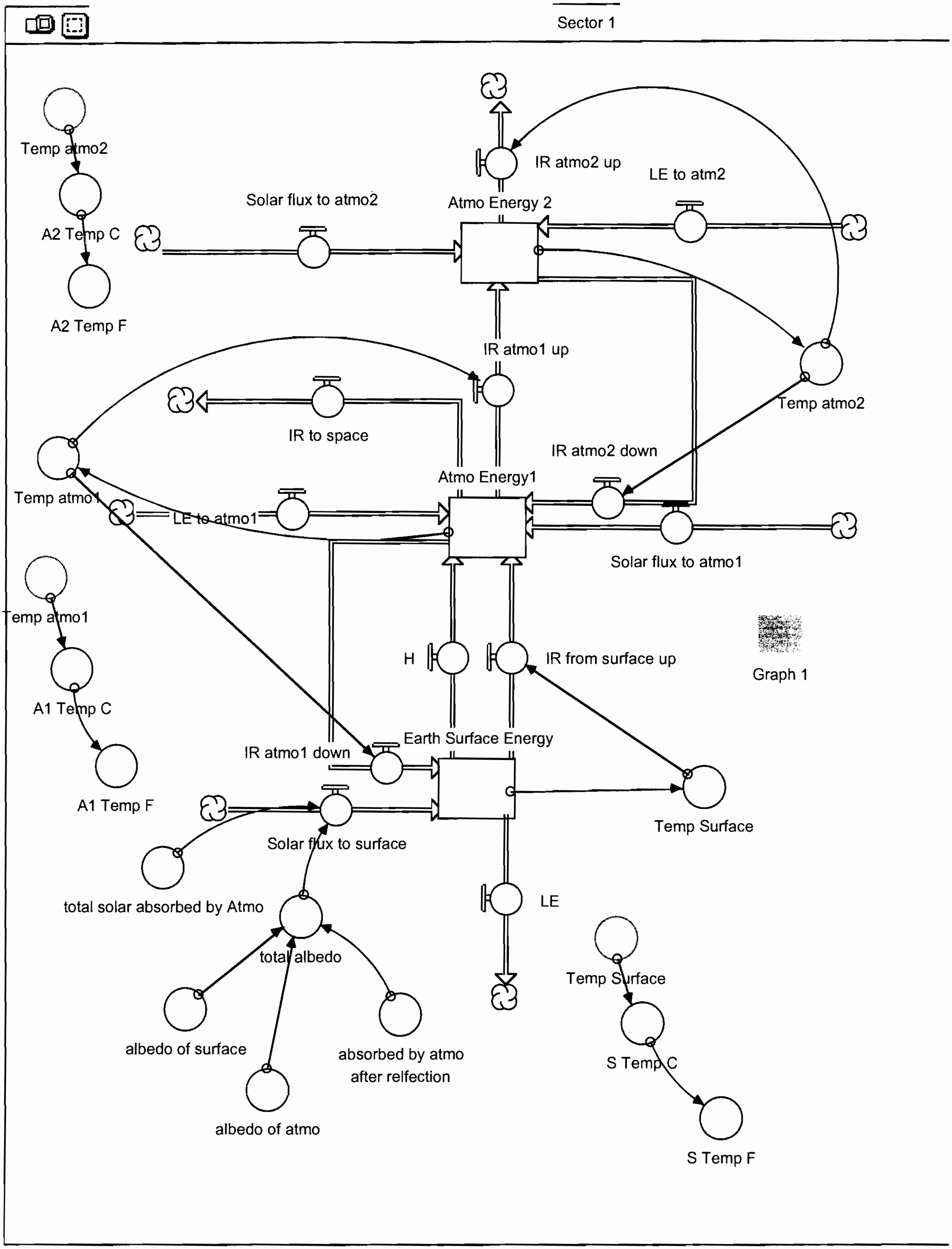
STELLA MODEL #1 (WITH SUBROUTINES)
FOR THE EARTH ENERGY BALANCE WITH NO ATMOSPHERE



STELLA MODEL #2

STELLA MODEL (with SUBROUTINES) for the EARTH ENERGY BALANCE WITH a ONE-LAYER ATMOSPHERE




Sector 1
Temp atmo2
A2 Temp C
A2 Temp F
IR atmo2 up
LE to atm2
Solar flux to atmo2
Atmo Energy 2
IR atmo1 up
Temp atmo2
IR to space
IR atmo2 down
Atmo Energy1
Temp atmo1
LE to atmo1
Solar flux to atmo1
Temp atmo1
A1 Temp C
A1 Temp F
H
IR from surface up
Graph 1
Earth Surface Energy
IR atmo1 down
Temp Surface
Solar flux to surface
total solar absorbed by Atmo
LE
total albedo
Temp Surface
S Temp C
S Temp F
albedo of surface
absorbed by atmo
after relfection
albedo of atmo