COMPUTER METHODS AND MODELING IN GEOLOGY
MODELING EARTH'S TEMPERATURE

In this week's lab we will learn how to create hierarchies of models of increasing complexity to understand some physical process - in this case, the absorption of solar energy by the Earth and its radiation of that energy back to space. Whenever you set out to understand a complex phenomenon, it is best to start with the simplest possible model that explains most of the behavior of that phenomenon and to build upward in complexity gradually. We will see how to do this today by modeling the energy balance at Earth's surface. We will first assume that the Earth is a perfect black body lacking an atmosphere, then move on to incorporate the fact that Earth reflects much of the solar radiation incident upon it, and later incorporate the fact that Earth has an atmosphere. Each time we build on to our model we will evaluate the output and compare it to actual Earth surface conditions to see how well each model refinement captures the reality of the physics of heat absorption, exchange, and emission.

Readings

Graedel, T.E., and Crutzen, P.J., 1993, Atmospheric Change: An Earth System Perspective, New York: W.H. Freeman and Company, 446 p.

Harte, J., 1988, Consider a Spherical Cow, Sausalito, CA: University Science Books, p. 69-72, p. 160-167.

Exercises

1) Using the first Harte reading (p. 69-72) create a Stella model of an Earth that behaves like a perfect black body. Use the Stefan-Boltzmann law to determine what Earth's surface temperature would be given the values of the solar constant and the Stefan-Boltzmann constant reported in the reading. Report your results in both Kelvin and Celsius units, and paste a copy of your model into your word file. How do your results compare to Earth's actual average surface temperature?

2) Now add a little more complexity to your model. Incorporate the fact that Earth is not a perfect absorber of solar radiation, but instead reflects a sizable portion of the energy incident upon it. What do you predict will happen to Earth's surface temperature? Was your prediction correct? How does the new surface temperature compare to Earth's actual average surface temperature? Paste a copy of your new model into your word file so I can see how you've modified your model.

3) To this point we have neglected the fact that Earth has an atmosphere. From your Harte and Graedel and Crutzen readings you learned that Earth's atmosphere is transparent to most of the incoming radiation given off by the sun, which is in the visible part of the light spectrum, but that it is largely opaque to the infrared radiation emitted by Earth's surface. The re-radiation of energy absorbed by the atmosphere down to the surface causes Earth's surface to be warmer than it would be in the absence of an atmosphere, and is an important variable we cannot neglect.

Add a one-layer atmosphere (following the methodology outlined in Harte, pg. 160-167, but using only 1 layer rather than n layers) to your model. Assume that all of the radiation given off by Earth's surface is absorbed by the atmosphere, but that none of the incoming solar radiation is absorbed. Determine the resulting temperature of Earth's surface and of the atmosphere. Paste your Stella model into your word document so I can see how you've changed your model.

4) Now add a second layer to your atmosphere as described in Harte (his n on pg. 163-164 is the number of layers in the atmosphere). How is the surface temperature affected by this change? How does the modeled surface temperature compare to the actual surface temperature of Earth?

5) You have now created a pretty sophisticated model of the Earth's energy balance. However, the values of temperature you're getting are too hot. What components of the energy balance have we neglected to this point? Hint: the neglected parts are discussed in the second Harte reading.

6) Incorporate these remaining elements into your model. Show me your final model and report the temperature of Earth's surface and the 2 atmospheric layers.

7) Now that your model is complete, let's run some experiments to see what might happen to Earth's temperature under different climatic scenarios.

a) Global warming scenario. Climatologists believe that increasing the concentration of greenhouse gases that absorb the infrared radiation given off by Earth will lead to an increase in Earth's surface temperature. Adjust your climate model to decrease the amount of radiation lost from Earth's surface directly to space by half. What is the impact on both the temperature of the atmosphere and of Earth's surface?

b) One of the possible impacts of global warming is an increase in cloud cover. The warmer temperature of Earth will likely enhance the hydrologic cycle, leading to more water vapor in the atmosphere and a greater abundance of clouds. What impact might this have on Earth temperature? Modify your model to explore this problem, keeping the global warming scenario above intact. Please explain the reasoning behind the changes you make.

c) Finally, explore the potential impact of the sunspot cycle on Earth temperature (set your model conditions back to the pre-global warming scenario). Allow the solar radiation reaching Earth's surface to change by +/- 1%, using a sine wave with period 11 years. First tell me what the equation is for this fluctuating radiation output. Then incorporate it and describe the impact on Earth's surface and atmospheric temperatures.