ENV 415 / ATM 415: Climate Laboratory, Spring 2016
Assignment 2

Answer all four questions. There is also an optional bonus problem.
Due Thursday February 18 by 10:15 am.
You may submit your answers by email (brose@albany.edu) or on paper at the start of class.

Question 1: (*Primer section 2.7, Review question 1)*

List all the components that *must* be included in a climate model and then add to this list a set of components that *could be* incorporated. How have you differentiated between the 'must' and the 'could be' components? Can you think of a different type of climate model for which you write a different list of 'must include' components? If you can, what does that mean?

Question 2: (*Primer section 2.7, Discussion question 3)*

Climate 'sensitivity' and climatic 'feedback' are two fundamental concepts in climate science and hence in climate modelling. If asked to explain these two terms, would your explanation use one to define the other? If you linked them, why did you, and, if you did not, why not?

Question 3:

Using our zero-dimensional EBM:

$$C \frac{dT}{dt} = ASR - OLR$$
$$ASR = (1-\alpha)Q$$
$$OLR = \tau_0 \, \sigma T^4$$

with parameter values:

- $C = 4\times10^8$ J m^{-2} K^{-1} is the heat capacity
- $\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4} is the Stefan-Boltzman constant
- $\tau_0 = 0.612$ is the atmospheric transmissivity before adding greenhouse gases
- $Q = 342$ W m^{-2} is the global average incoming solar radiation

a) First suppose (as we have already done) that the planetary albedo is fixed at $\alpha = 0.3$. Doubling CO2 decreases the transmissivity τ_0 from 0.612 to 0.602. **Calculate the radiative forcing** (in W m^{-2}) due to this decrease.
b) Calculate no-feedback response to this forcing (what we called ΔT_0 in class).
c) We now add a parameterization of the **water vapor feedback**. As the temperature warms, the atmosphere holds more water vapor, and this causes the transmissivity to decrease further. Use these formulas:

$$OLR = \tau(T) \, \sigma T^4$$

with the water vapor effect given by

$$\tau(T) = \tau_0 - \frac{(T - 288\,K)}{250\,K}$$

Write a Python function to implement the above formula for τ as a function of temperature. Show your code.

d) **Use numerical timestepping to find the new equilibrium temperature**, including the water vapor feedback. Make sure that you iterate (time-step) enough times that your model is very close to equilibrium. Show the code you used to calculate the new equilibrium temperature. What is equilibrium warming ΔT_{eq}?

e) Based on your answers from (b) – (d), **calculate the system gain g** due to the water vapor feedback, and the corresponding **water vapor feedback amount** (call it f_w).

Question 4

Now consider the **surface ice/snow albedo feedback**: warming (cooling) leads to reduced (increased) ice and snow, which leads to reduced (increased) planetary albedo. We will represent this by making the planetary albedo in our model a function of global mean temperature, $\alpha = \alpha(T)$. Specifically, use this function:

$$\alpha(T) = \begin{cases} \alpha_i & T \leq T_i \\ \alpha_o + (\alpha_i - \alpha_o)\dfrac{(T - T_o)^2}{(T_i - T_o)^2} & T_i < T < T_o \\ \alpha_o & T \geq T_o \end{cases}$$

with parameter values $\alpha_o = 0.289, \alpha_i = 0.7, T_o = 293\ K, T_i = 260\ K$. Note that this formula reproduces the observed albedo for T = 288 K.

a) **Write a Python function** that implements the formula above for $\alpha(T)$. Show your code.

b) Use this function to **produce a figure plotting ASR for temperatures ranging from 250 K to 310 K**. Add axis labels to indicate what is plotted. Show the code you used to make the figure. Comment on the shape of the graph.

c) Repeat question 3(d), this time **including the albedo feedback but ignoring the water vapor feedback** (i.e. tau does not decrease with temperature). Again, use numerical timestepping to **calculate the new equilibrium temperature** after the increase in greenhouse gases, including the albedo feedback. Show your code, and make sure that you iterate enough times to ensure your solution is very very close to equilibrium.

d) Repeat equation 3(e), calculating the system gain g due to ice albedo feedback and the corresponding feedback amount f_i.

e) Now repeat the whole process, but this time **include both water vapor and albedo feedback**. Timestep to equilibrium and calculate the new equilibrium temperature. Do you get more or less warming when both feedbacks are included?

f) Calculate the system gain g due to the combined effects of water vapor and albedo feedbacks, and the combined feedback amount f.

g) Are the feedback amounts additive? In other words, do you find that $f = f_w + f_i$? Are the system gains additive? Comment on why / why not.

Bonus problem *(open-ended investigation for extra credit, not required)*

Something very different occurs in this model if you introduce a strong negative radiative forcing, either by substantially reducing greenhouse gases (which we would represent as an increase in the transmissivity τ_0), or by decreasing the incoming solar radiation Q.

Investigate, using your numerical model code, and report your results along with your thoughts.