ATS 630, Energy Balance Model Homework #2, Due 16 Oct 2023

The $EBM3_o$ you have constructed at present allows transfers of energy only by radiation (photons). Each layer is in balance between the total solar energy absorbed and the net thermal emission lost:

$S_1 = L_1$
$S_2 = L_2$
$S_3 = L_3$

According to Table 1 in the handout which documents the EBM, the non-radiative transfer of energy from the surface to the lowest atmospheric layer is equivalent to 0.287Q. This heat flux is the sum of the energy transferred from the surface to the lowest atmospheric layer by latent and sensible heat flux.

Rewriting the equations now, the model which includes the non-radiative component would be:

$S_1 = L_1$
$S_2 = L_2 - HF$
$S_3 = L_3 + HF$

Note for example that L_2 is the net thermal radiative loss for layer 2, so HF is a counterbalance to that value and is of the opposite sign.

Recall $Q = 341\ Wm^{-2}$ and $\sigma = 5.673 \times 10^{-8}$.

Problem 1: Include the value of HF in your $EBM3_o$ model and recalculate the temperatures of the three layers using the radiative transfer coefficients applied in the first homework assignment (i.e. far right column of Table 2). This basic version of your model, which includes HF, will be known as $EBM3_{HF}$.

Problem 2: Use the radiation coefficients of Kiehl & Trenberth 2 and solve for the temperatures of the three layers (include HF.)

Problem 3: For this problem, use your $EBM3_{HF}$ radiative transfer coefficients from Problem 1 above **with the HF component included** (i.e. $EBM3_{HF}$). The task is to mimic a changing greenhouse effect within a single atmospheric layer in this model. Start with $EBM3_{HF}$ but with $a_2 = 0.720$, then increase a_2 by steps of 0.002 from 0.710 to 0.770 while at the same time reducing the transmissivity t_2 from 0.075 to 0.015 while leaving r_2 the same (i.e. $a_2 + t_2 = 0.785$). Solve for the temperature of the three layers as a_2 and t_2 change by small increments. Plot the results with the absorption a_2 on the x-axis and the temperatures on the y-axis. What is the effect of making the troposphere (level 2) more absorptive to thermal radiation on all levels (i.e. analogous to increasing the greenhouse effect)?

What is the average linear rate of surface temperature change (ΔT_3) relative to a change in a_2 (Δa_2) over this range (i.e., $\Delta T_3/\Delta a_2$)?

What are the rates of change for T_1 and T_2, (i.e. $\Delta T_1/\Delta a_2$, and $\Delta T_2/\Delta a_2$)?

What happens to the tropospheric lapse rate (T_3-T_2) as a_2 increases? What else could change (feedback) that would keep the tropospheric lapse rate near that of the base case (Problem 1)?

Problem 4. Begin with $EBM3_{HF}$ of Problem 1 and change the value of a_1 to mimic an increase in greenhouse gases in the stratosphere. In this case, start with a_1 at 0.070 and increase by 0.002 increments to 0.120. Reduce t_1 by the same amount, leaving r_1 unchanged at 0.005 (so $a_1 + t_1 = 0.995$). Plot the values with a_1 on x-axis and temperatures on y-axis.

What is the average linear rate of surface temperature change (ΔT_3) relative to a change in a_1 (Δa_1) over this range ($\Delta T_3/\Delta a_1$)?

What is the rate of change for T_1 and T_2, (i.e. ($\Delta T_1/\Delta a_1$, and $\Delta T_2/\Delta a_1$)?