Name: ______________________________

ATOC/ASTR 5560 Radiative Processes — Lab 11
December 7, 2001

The purpose of this lab is to learn about radiative-convective equilibrium (RCE) models and climate sensitivity. We will use a radiative-convective equilibrium model built around the NCAR Community Climate Model (CCM3) Radiation Model (CRM) (`http://www.cgd.ucar.edu/cms/crm/`). This fast and accurate broadband radiative transfer model has been converted to a subroutine `crmsub` for use by the RCE model and a standalone driver program. The source code is available on nit in `/home/rt/rce/rce_crm.tar.gz`.

Log in to nit and copy the following files to your directory:

`/home/rt/rce/run_crm`	CRM driver executable
`/home/rt/rce/rce_crm`	RCE model executable
`/home/rt/rce/rce_crm.F`	RCE model source code
`/home/rt/rce/global.in`	CRM input file
`/home/rt/rce/plottemp.pro`	IDL file for plotting `rce_crm` profiles

1. The CRM driver program `run_crm` and the RCE model `rce_crm` both read the CRM standard input file. The input file `global.in` is set up with a global average atmospheric profile (US standard atmosphere). It has time and latitude parameters to give a solar zenith angle of 60° ($\mu_0 = 0.5$), which is the correct global daytime average solar zenith angle. The surface albedo is set to 15% to obtain a reasonable clear sky shortwave albedo. The input profile contains a low altitude cloud layer and a high altitude cloud layer, but initially with zero cloud fraction.

   You will adjust some parameters in `global.in` to tune the simulation for current Earth mean radiative fluxes. Run the CRM driver program using

   ```
   run_crm < global.in >!  global.out
   ```

   a) Since we are trying to simulate a global and time average, we need to change the solar constant from its usual value. Adjust the solar constant in `global.in` to achieve the correct global mean solar insolation. Verify the correct mean solar insolation in the `run_crm` output file. How do you need to change it and why?

   b) Adjust the cloud fractions of the low cloud ($p = 795$ mb $W = 75$ g/m^2) and high cloud ($p = 227$ mb, $W = 10$ g/m^2) to get the correct (within measurement error) global mean top of atmosphere shortwave albedo and outgoing longwave flux. Do not change the cloud liquid water paths. What are the two cloud fractions you get?

c) Qualitatively, how do the *low* and *high* clouds change the shortwave, longwave, and total radiative heating rates in the cloud layers.

d) With the final global configuration what is the net shortwave + longwave flux at the surface? Where and how is this net energy transferred?

2. Now look at the radiative-convective equilibrium model `rce_crm.F`. Please briefly answer the following questions about the RCE model.

   a) What is the radiative equilibrium solution method (i.e. how is equilibrium achieved)?

   b) Describe the convective adjustment procedure.

d) How is the water vapor feedback implemented?

3. Now run the RCE model. A time step of 1 day works fine.

   You may run the RCE model interactively, by just typing its name `rce_crm`. Or, to quickly run several cases you can use the `put` command:

```
put global.in F F F 1.0 0.005 1000 global_re.out | rce_crm
put global.in T 6.5 F F 1.0 0.005 1000 global_rce.out | rce_crm
```

   a) Run the following cases using your global mean input file:
   i) radiative equilibrium with no feedbacks,
   ii) radiative equilibrium with water vapor feedback,
   iii) radiative-convective equilibrium with no feedbacks,
   iv) radiative-convective equilibrium with water vapor feedback.
   For all RCE cases in this lab use a critical lapse rate of 6.5 K/km.
   Plot the four output temperature profiles with `plottemp.pro`.

   b) Explain the features in the radiative equilibrium (no feedback case) temperature profile: Why does the radiative equilibrium temperature profile change so rapidly in the lower atmosphere? Why is there a feature around 10 km? What causes the temperature increase above 15 km?

c) List the height and pressure ranges of the radiative-convective equilibrium profile that are in radiative equilibrium. What do we call the convectively adjusted and radiative equilibrium regions?

d) How good is the radiative-convective equilibrium model with the water vapor feedback at predicting the global mean temperature profile?

4. Find the climate sensitivity with no feedbacks and with the water vapor feedback by changing the solar constant 5%. Make a new CRM input file (e.g. `globalsun.in`). Compare the original and new solar constant surface temperatures for the radiative-convective equilibrium model ($\Gamma_c = 6.5\ \mathrm{K/km}$). You will need four runs so you can compare the two no feedback cases and then the two water vapor feedback cases. For this precision work set the convergence criterion (maximum temperature change) to 0.001 K/day.

   a) List the surface temperatures for the four cases and your derived climate sensitivities [K/(W/m^2)]. How does the no feedback climate sensitivity compare with that derived simply in the homework?

b) Explain why the climate sensitivity is different with the water vapor feedback.

5. Now investigate the famous doubling of CO_2 experiment. Make a new CRM input file (e.g. `global2co2.in`) with the doubled CO_2 concentration.

   a) Use `run_crm` to find radiative forcing from $2 \times \mathrm{CO_2}$ at the tropopase (210 mb level).

   b) Do a sequence of four climate change experiments using the radiative- convective equilibrium model. Each experiment has a control run ($1 \times \mathrm{CO_2}$) and a climate change run ($2 \times \mathrm{CO_2}$). Again use the 0.001 K/day max temperature change criterion. The experiments are:

   i) No feedbacks, ii) water vapor feedback alone, iii) high cloud fraction feedback alone, and iv) water vapor and high cloud feedbacks.

   For the high cloud feedback hypothesize that global warming causes increased thunderstorm convection leading to more cirrus cloudiness. Assume that the high cloud fraction increases by 0.03 per K of surface temperature change (and no change in low cloud).

   Make a table with the surface temperatures and the ΔT for each experiment.

   c) Plot the temperature profiles for the control run and doubled CO_2 run for just the water vapor feedback experiment. Where is the temperature change most notable? Which direction is this change and why?

d) Calculate the feedback factor f for the three feedback experiments. How well does linear control theory work in this case? Compare adding the feedback factor f with the simple notion of adding temperature changes due to the combined water vapor and cloud feedbacks.