Project 2, ATS622
Due Friday May 1, 2015

Basic Overview of the Project

In this project, you will use a simple "off-the-shelf" broadband radiation code developed at CSU to calculate shortwave (SW) and longwave (LW) fluxes and heating rates for model atmospheric profiles. In doing so, you will

- Gain understanding of what flux & heating rate profiles look like.
- Learn how net fluxes in the shortwave and longwave connect to local heating rates.
- Explore how these flux & heating rates change due to changes in atmospheric constituents, such as changes in the gas amounts (water vapor, CO_2, ozone) and in clouds.

This project can be almost entirely done online, with the GUI-based version of "BUGSrad": http://biocycle.atmos.colostate.edu/shiny/BUGSrad_ats622/

The model makes the following assumptions:

- The longwave surface emissivity is unity.
- The shortwave albedo is independent of wavelength and is Lambertian (independent of input ray direction, and identical at all output directions).
- The CO_2, H_2O, and N_2O profiles are flat.
- You can add up to one water cloud and one ice cloud.

Detailed Steps

1. **Go to the website and play with the interactive tool.**
   The "Control" button allows to modify the control case. It is based on the clear-sky atmospheric scenario from the chosen atmospheric profile. There are 5 default atmospheric profiles, based on the semi-famous "McClatchey Profiles". Each has been assigned default surface albedos and solar zenith angles, but you can change those. The only thing you cannot change is the temperature profile (including the surface temperature) and the shape of the water vapor and ozone profile.
   - Tropical (TCWV = 40.4 kg/m^2)
   - Midlatitude Summer (TCWV = 28.9 kg/m^2)
   - Midlatitude Winter (TCWV = 8.6 kg/m^2)
   - Subarctic Summer (TCWV = 20.7 kg/m^2)
   - Subarctic Winter (TCWV = 4.2 kg/m^2)

   Should you wish to make your own plots, it is very easy. Simply download the output by clicking on the "Model Output" tab, and click "Download" to grab a comma-delimited file containing the flux & heating rate output.

Try all of the profiles. Try things like changing the surface albedo, changing the the solar zenith angle, removing the ozone or water vapor, etc.

2. **Analyze two baseline profiles**

Choose two of the five baseline profiles and show the net flux and heating rate profiles (either via screen capture, or by downloading and plotting the output yourself). Then answer the following questions:

- How do the profiles change with the sun high in the sky vs. low in the sky? What is the solar zenith angle that achieves radiative equilibrium at TOA? At the surface? If they are different, why? Be sure to comment on the LW vs. SW aspects.
- In the default configuration, if these were the only forces driving temperature changes, how would the temperature profiles and surface temperatures respond? How might convective and latent heat processes alter these projected changes?
- Comment on the differences of the next flux & heating rate profiles of the two different profiles you chose. Which will be driven to heat faster or slower, and where (due to radiation)?
- For the moister case, comment on the LW cooling in the lower atmosphere. Based on our class discussion, what is the primary process driving this? What causes the funny double-dip shape of the cooling profile?

3. **Run perturbed cases**. For one of the two default profiles, you will run perturbed cases as follows (only run a single perturbation at a time; do not combine perturbations).

   a. Increase water vapor abundance throughout the profile by 20%.
   b. Double CO_2
   c. Reduce the ozone abundance by 50%.
   d. Add a low water cloud from 700 to 900 hPa with a CWC of 0.3 g/kg. (Also please calculate and tell me what is the rough liquid water path, in g/m^2, of the cloud).
   e. Add a thin ice cloud from 100-150 hPa, with an IWC of 0.1 g/kg.

Before you run any of the perturbations, guess how the SW & LW fluxes and heating rates will change (qualitatively) and what will be the dominant factor (and include your guesses in your write-up). Do this for each of the 5 perturbation cases.

4. **An experiment of your choice.** Create a baseline & perturbations case to test out some hypothesis or idea of your own. Be creative. Some possible ideas:
   a. See how the forcing due to doubled CO_2 is impacted by the presence of water vapor and ozone (by removing them altogether, one by one and together).

b. Set up a situation as close as possible to the global average, and examine how the radiation budget terms compare to those given in a standard earth energy budget(e.g., Trenberth et al., 2009, Wild et al., 2012).

5. **Plots & analysis**.

Plots: For each of the two baseline runs, make a profile plot for the SW net, LW net, and (SW+LW) net flux. That is, flux on the x-axis, pressure on the y-axis. Do this twice: once using a scale linear in pressure, once using a scale logarithmic in pressure. Different features will jump out at you for each. Then, make similar plots for the heating rates (SW, LW, and total). Thus, four plots in all for each of the two baseline cases. **You may make your own plots or take screen-shots from the web page.**

Repeat this approach for the perturbation cases, but instead of the absolute net fluxes and heating rates, plot the DIFFERENCE FROM THE BASELINE RESULT. These represent the forcings due to the changes in the constituents.

If you are creative, you can get all plots on one page for each case. Making plots that convey maximum information but without making them too busy is an art in science and one that you will learn to cultivate; this project will give you plenty of practice!

Compile all your plots, and for the base runs and perturbations, comment on the results. Do the changes in forcings and heating rates agree with your initial guesses?

For each baseline case, comment on the TOA, atmospheric, and surface forcing. Do they make physical sense? Then for each perturbation, discuss:

- Is the earth system being heated or cooled (positive or negative TOA forcing)?
- How is this heating or cooling distributed between the atmosphere & surface, and any cloud layers present?
- How would the atmosphere react to this instantaneous forcing? I.e., how would the temperature profile want to change, would this cause convection that might lead to additional changes somewhere? What would happen if these heating or cooling rates were sustained for a couple of hours?

6. **Write-up.**

Your write-up should include the following components:

- Abstract: A brief summary of the work described in your write-up along with key findings. This is often written last.

- Introduction: An overview of what you did.
- Methods: A very brief outline how you will use the online BUGSrad to determine the quantities of interest and what set of experiments you will run.
- Results – This is where you will put your figures and analysis. You should use subsections to organize your results, and in each subsection, you should provide a written description of the key features or behavior you observe.
- Conclusions – Summarize what you think are the most important findings in your results section, and provide some context if you can. In addition, describe any additional experiments that you think would be interesting. Finally, state what you personally learned from this project!
- References – Any relevant references for this project.

NOTES

REFERENCES FOR BUGSrad:

Fu, Q., and K-N. Liou, 1992: On the correlated *k*-distribution method for radiative transfer in nonhomogeneous atmospheres. *J. Atmos. Sci*, **49,** 2139–2156.

Stephens, G L., P M. Gabriel, and P T. Partain, 2001: Parameterization of atmospheric radiative transfer. Part I: Validity of simple models. *J. Atmos. Sci*., **58,** 3391–3409.

SOME BACKGROUND

- A doubling of CO2 is expected to increase downwelling forcing at 200 mbar by about 5.3 W/m^2. See e.g.

Collins, W. D., et al. "Radiative forcing by well-mixed greenhouse gases: Estimates from climate models in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4)." *Journal of Geophysical Research: Atmospheres (1984–2012)* 111.D14 (2006).

- Radiation budget papers
    - Trenberth, Kevin E., John T. Fasullo, and Jeffrey Kiehl. "Earth's global energy budget." *Bulletin of the American Meteorological Society* 90, no. 3 (2009): 311-323.
    - Loeb, Norman G., et al. "Toward optimal closure of the Earth's top-of-atmosphere radiation budget." *Journal of Climate* 22.3 (2009): 748-766.
    - Stephens, Graeme L., et al. "An update on Earth's energy balance in light of the latest global observations." *Nature Geoscience* 5.10 (2012): 691-696.

- There is currently some argument above what the global mean downwelling longwave flux is at the surface. Part of this argument stems from uncertainties in cloud measurements. See:

  Stephens, Graeme L., et al. "The global character of the flux of downward longwave radiation." *Journal of Climate* 25.7 (2012): 2329-2340.