Lab #4 Exercises

Lapse Rates, Clouds, and Water-Vapor Feedback

put your name here

Lab: Mon. Sept. 17. Due: Mon. Sept. 24.

Contents

General Instructions

In the past three weeks, we focused on mastering many of the basics of using R and RMarkdown. For this week's lab, when you write up the answers, I would like you to think about integrating your R code chunks with your text.

For instance, you can describe what you're going to do to answer the question, and then for each step, after you describe what you're going to do in that step, you can include an R code chunk to do what you just described, and then the subsequent text can either discuss the results of what you just did or describe what the next step of the analysis will do.

This way, your answer can have several small chunks of R code that build on each other and follow the flow of your text.

Chapter 5 Exercises

For this model, you will use the RRTM model, which includes both radiation and convection.

Exercise 5.1: Lapse Rate

Run the RRTM model in its default configuration and then vary the lapse rate from 0 to 10 K/km. For each value of the lapse rate, adjust the surface temperature until the earth loses as much heat as it gains (i.e., the value of Q in the `run_rrtm` model output is zero.)

It will probably be easier to do this with the interactive version of the RRTM model at http://climatemodels.uchicago.edu/rrtm/ than with the R interface `run_rrtm`.

a) Make a tibble containing the values of the lapse rate and the corresponding equilibrium surface temperature, and **make a plot** with lapse rate on the horizontal axis and surface temperature on the vertical axis.

Answer: *Put your answer here.* Be sure to show your work and include any data, plots, etc. that you need in order to explain how you came up with your answer. Integrate the code chunks with your text, so you explain what you are doing and then present the code that executes that part of your work.

```
# Here is an example of running rrtm_default.
# Modify it and add additional code to do this exercise.
#
rrtm_default = run_rrtm(file = "_data/rrtm_default.Rds", T_surface = 284.42,
                        lapse_rate = 6, co2 = 400)
rrtm_default$Q # Energy imbalance: positive means more heat in than out,
```

```
## [1] 0
```

```
                # negative means more heat out than in.

rrtm_changed = run_rrtm(file = "_data/rrtm_default.Rds", T_surface = 284.42,
                        lapse_rate = 7, co2 = 400)
rrtm_changed$Q # Energy imbalance: positive means more heat in than out,
```

```
## [1] 1
```

```
                # negative means more heat out than in.
```

For example, you could write: For a lapse rate of 7. K/km, the heat imbalance is 1.0 W/m^2. That means that we need to raise the surface temperature.

Note how I use the R function `ifelse` to automatically choose between "raise" and "lower" in the text.

b) Describe how the equilibrium surface temperature varies as the lapse rate varies.

Answer: *Put your answer here.* Be sure to show your work and include any data, plots, etc. that you need in order to explain how you came up with your answer. Integrate the code chunks with your text, so you explain what you are doing and then present the code that executes that part of your work.

```
# If you need to, intersperse code chunks in your answer to show your work.
# If you can answer this part without needing R code, you don't need to include
# code chunks.
```

Chapter 7 Exercises

Exercise 7.2: Clouds and Infrared.

Note: this exercise only considers the effect of clouds on longwave radiation and ignores the effect of clouds on albedo, which is also important.

a) Run the MODTRAN model with present-day CO_2 (400 ppm) and a tropical atmosphere. Plot the outgoing infrared spectrum.

   Run MODTRAN four times: first with no clouds, and then with three different kinds of clouds: standard cirrus, altostratus, and stratus. These correspond to high, medium, and low-altitude clouds.

   Describe the important differences between the spectra for the four cases. Describe the differences in the intensity of outgoing infrared radiation I_{out} for the four cases.

   How do the four spectra compare for the 700 cm^{-1} band (where CO_2 absorbs strongly) and the 900 cm^{-1} band (in the atmospheric window)?

   Which kind of cloud has the greatest impact on outgoing infrared light? Why?

Answer: *Put your answer here.* Be sure to show your work and include any data, plots, etc. that you need in order to explain how you came up with your answer.

```
# Mix code chunks with your text to show your work
```

b) Now set `atmosphere` to `"midlatitude winter"`, set `clouds` to `"none"`, and set the sensor altitude to 0 km (`altitude_km = 0`) and make the sensor look up (`looking = "up"`). This means your sensor is on the ground looking up at the longwave radiation coming down from the atmosphere to the ground instead of looking down from the top of the atmosphere at the longwave radiation going out to space.

   Run MODTRAN first with `h2o_scale = 1` (the default), and then with `h2o_scale = 0` (no water vapor).

   Plot the two spectra and compare them. Discuss why you see what you see:

   - For the atmosphere with no water vapor, compare the parts of the spectrum corresponding to the strong CO_2 absorption (roughly 600–750 cm^{-1}) and the infrared window (roughly 800–1200 cm^{-1}).
     - Which corresponds to higher emission temperatures and which to lower temperatures?

- Why do you think this is?

- For the atmosphere with normal water vapor (`h2o_scale = 1`), how does water vapor change the spectrum you see from the ground?
  - Does it make the longwave radiation brighter (warmer) or dimmer (cooler)?
  - Why do you think this is?

Answer: *Put your answer here.* Be sure to show your work and include any data, plots, etc. that you need in order to explain how you came up with your answer.

```
# Mix code chunks with your text to show your work
```

c) Keeping the same settings for `atmosphere = "midlatitude winter"`, `altitude_km = 0`, and `looking="up"`, set `h2o_scale=1` and run MODTRAN first with no clouds, then with three kinds of clouds: standard cirrus, altostratus, and stratus (`clouds="none"`, `clouds="standard cirrus"`, `clouds="altostratus"`, and `clouds="stratus"`).

When we're looking up at the clouds, the base (bottom) of the clouds form a layer that is opaque to longwave radiation, with an emissivity of 1 (i.e., a perfect black body).

Cirrus clouds are very high (around 10 km above sea level), altostratus clouds are at a medium height (with a base around 2.4 km), and stratus clouds are very low (with a base around 0.33 km).

For each run examine
I_{down}. (Remember that the variable `i_out` in the MODTRAN output measures the intensity of longwave radiation reaching the sensor. In this exercise, the sensor is on the ground looking up, so `i_out` measures the downward radiation reaching the ground.)

Describe how I_{down} compares for the four conditions.

```
* Do the clouds have a heating or cooling effect?
* Which clouds have the greatest effect?
* What does this suggest about how clouds affect the ground temperature?
```

As you do this exercise, think about a winter night with clear skies versus a winter night with cloudy skies.

Answer: *Put your answer here.* Be sure to show your work and include any data, plots, etc. that you need in order to explain how you came up with your answer. Integrate the code chunks with your text, so you explain what you are doing and then present the code that executes that part of your work.

```
# Mix code chunks with your text to show your work...
```

d) Plot the longwave radiation spectra for the four MODTRAN runs from part (c). Which parts of the spectrum do the different clouds affect the most? (Compare the infrared window to the parts of the spectra where CO_2 absorbs.)

- Look at two parts of the spectrum: the infrared window (roughly 800–1200 cm^{-1}) and the region where CO_2 absorbs strongly (roughly 600–750 cm^{-1}).

Why do you suppose the high, medium, and low clouds affect the two different spectral regions the way they do?

- In which part of the spectrum do the clouds affect the downward longwave radiation the most?

Answer: *Put your answer here.* Be sure to show your work and include any data, plots, etc. that you need in order to explain how you came up with your answer.

```
# Mix code chunks with your text to show your work
```

Exercise 7.3: Clouds and Visible Light.

For this exercise, you will use the RRTM model to examine climate sensitivity and the water vapor feedback in a radiative-convective atmosphere.

a) First, run the RRTM model with its default parameters (400 ppm CO_2) and note the surface temperature (`T_surface`).

   Then run it again with doubled CO_2 concentration (`co2 = 800`). Adjust the surface temperature to bring the heat imbalance `Q` to zero (it may be easier to do this with the interactive model at http://climatemodels.uchicago.edu/rrtm/ and then paste the new surface temperature into your R code).

   The change in surface temperature between the 400 ppm CO_2 and 800 ppm CO_2 ($\Delta T_{2\times \mathrm{CO}_2}$) runs is the **climate sensitivity**. What is it?

Answer: *Put your answer here.* Be sure to show your work and include any data, plots, etc. that you need in order to explain how you came up with your answer. Integrate the code chunks with your text, so you explain what you are doing and then present the code that executes that part of your work.

```
# Mix code chunks with your text to show your work...
```

b) Now run the RRTM model again, for 400 and 800 ppm CO_2, but this time setting `relative_humidity = 0` (this turns off the water vapor feedback). At each concentration of CO_2, adjust `T_surface` to bring the heat into balance (so the output has `Q` equal to zero). Now what is the climate sensitivity ($\Delta T_{2\times \mathrm{CO}_2}$)?

Answer: *Put your answer here.* Be sure to show your work and include any data, plots, etc. that you need in order to explain how you came up with your answer. Integrate the code chunks with your text, so you explain what you are doing and then present the code that executes that part of your work.

```
# Mix code chunks with your text to show your work...
```

c) Compare the climate sensitivity ($\Delta T_{2\times \mathrm{CO}_2}$) in part (a) (with water-vapor feedback) and part (b) (without water-vapor feedback). The amplification factor for the water-vapor feedback is the ratio of the climate sensitivity with water-vapor feedback to the sensitivity without the feedback. What is it?

Answer: *Put your answer here.* Be sure to show your work and include any data, plots, etc. that you need in order to explain how you came up with your answer. Integrate the code chunks with your text, so you explain what you are doing and then present the code that executes that part of your work.

```
# Mix code chunks with your text to show your work...
```