Instructions for Lab #5

Climate Feedbacks

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Exercises

These are the exercises you will work for the lab this week.

General Instructions

Just as with last week's lab, when you write up the answers, I would like you to integrate 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.

Exercise 1: 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 the default conditions: present-day CO_2 (400 ppm), a tropical atmosphere, and the sensor looking down from an altitude of 70 km. 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 (`clouds = "standard cirrus"`, `clouds = "altostratus"`, and `clouds = "stratus"`). These correspond to clouds at high, medium, and low altitude, respectively.

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 band of wavenumbers from about 600–750 cm^{-1} (where CO_2 absorbs strongly) and the band from about 800–1200 cm^{-1} (the atmospheric window)?

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

b) Keeping the default settings (sensor altitude = 70 km looking down), Set `atmosphere = "midlatitude winter"` and `h2o_scale=1` and run MODTRAN with no clouds.

Next, run MODTRAN with the same settings, but with `altitude_km = 0` and `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.

Plot the two spectra (looking down from 70 km and looking up from the ground) and describe what you see. Pay special attention to 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 parts of the spectrum correspond to warmer temperatures temperatures when you look down, and which parts correspond to colder temperatures? What about when you are looking up from the ground? Do you notice a pattern?

c) Now, run MODTRAN with the sensor looking up from the ground (`altitude = 0` and `looking = "up"`), but with stratus clouds (`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).

Make a note of I_{down} for the clear sky and with clouds. (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.)

Plot the spectra for both cases and also compare I_{down}.

- What part of the spectrum is most affected by clouds? (Answer both in terms of what ranges of wavelengths or wavenumbers are affected, and also what name we give to this part of the spectrum).
- On a winter night in Nashville, would it be colder if the sky is clear or if it's cloudy?

d) Now set `clouds` to `"none"`, and keep the sensor altitude at 0 km (`altitude_km = 0`) looking up (`looking = "up"`).

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

Plot the two spectra (with water vapor and without water vapor) 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 parts of the spectrum correspond 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?

Exercise 2: Water Vapor Feedback

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 ($\Delta T_{2\times CO_2}$) runs is the **climate sensitivity**. What is it?

b) Now run the RRTM model again, with 400 ppm CO_2, but this time setting `relative_humidity = 0` (this turns off the water vapor feedback). Adjust `T_surface` to bring the heat into balance (so the output has `Q` equal to zero). Note the value of `T_surface`.

Now double the CO_2 concentration (to 800 ppm) and adjust `T_surface` to bring the heat into balance. What is the climate sensitivity $\Delta T_{2\times CO_2}$ when there is no water-vapor feedback?

c) Compare the climate sensitivity ($\Delta T_{2 \times CO_2}$) 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 the amplification factor?

In your write-up, discuss how including the water vapor feedback changes the way that CO_2 affects the climate.