Instructions for Lab #5

The Geochemical Carbon Cycle

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Lab: Feb. 10; Due: Feb. 24

Contents

Carbon Cycle

For the following exercises, you will use the GEOCARB model, which simulates the earth's carbon cycle.

The GEOCARB model has two time periods:

- First, it runs for 5 million years with the "Spinup" settings in order to bring the carbon cycle and climate into a steady state.
- Then, at time zero, it abruptly changes the parameters to the "Simulation" settings and also dumps a "spike" of CO_2 into the atmosphere and runs for another 2 million years with the new parameters to see how the climate and carbon cycle adjust to the new parameters and the CO_2 spike.

The quantities that are graphed include:

pCO2 is the concentration of CO_2 in the atmosphere, in parts per million.
WeatC is the rate of CO_2 being weathered from carbonate rocks and moved to the oceans.
BurC is the rate of carbonate being converted into limestone and buried on the ocean floor.
WeatS is the rate of SiO_2 being weathered from silicate rocks and moved to the oceans.
Degas is the rate at which CO_2 is released to the atmosphere by volcanic activity
tCO2 is the total amount of CO_2 dissolved in the ocean, adding all of its forms:

$$\text{tco2} = [CO_2] + [H_2CO_3] + [HCO_3-] + [{CO_3}^{2-}].$$

alk is the ocean alkalinity: the total amount of acid (H^+) necessary to neutralize the carbonate and bicarbonate in the ocean. The detailed definition is complicated, but to a good approximation, alk $= [HCO_3-] + 2\,[CO_3{}^{2-}]$. This is not crucial for this lab.

CO3 is the concentration of dissolved carbonate ($CO_3{}^{2-}$) in the ocean, in moles per cubic meter.

d13Cocn is the change in the fraction of the carbon-13 (^{13}C) isotope, relative to the more common carbon-12 (^{12}C) isotope, in the various forms of carbon dissolved in the ocean water.

d13Catm is the change in the fraction of ^{13}C, relative to ^{12}C in atmospheric CO_2.

Tatm is the average air temperature.

Tocn is the average temperature of ocean water.

Note:

In this lab, you will mostly look at pCO2, but in exercise 8.2, you will also look at the weathering.

Running the GEOCARB model from R

I have provided functions for running the GEOCARB model from R:

To run the model:

```
run_geocarb(filename, co2_spike, degas_spinup, degas_sim,
plants_spinup, plants_sim, land_area_spinup, land_area_sim,
delta_t2x, million_years_ago, mean_latitude_continents)
```

You need to specify `filename` (the file to save the results in) and `co2_spike` (the spike in CO_2 at time zero).

The other parameters will take default values if you don't specify them, but you can override those defaults by giving the parameters a value.

`degas_spinup` and `degas_sim` are the rates of CO_2 degassing from volcanoes for the spinup and simulation phases, in trillions of molecules per year.

`plants_spinup` and `plants_sim` are `TRUE/FALSE` values for whether to include the role of plants in weathering (their roots speed up weathering by making soil more permeable and by releasing CO_2 into the soil), and `land_area` is the total area of dry land, relative to today. The default values are: `degas` = 7.5, `plants` = `TRUE`, and `land_area` = 1.

The geological configuration allows you to look into the distant past, where the continents were in different locations and the sun was not as bright as today.
`delta_t2x` is the climate sensitivity (the amount of warming, in degrees Celsius, that results from doubling CO_2). `million_years_ago` is how many million years ago you want year zero to be and `mean_latitude_continents` is the mean latitude, in degrees, of the continents (today, with most of the continents in the Northern hemisphere, the mean latitude is 30 degrees).

After you run `run_geocarb`, you would read the data in with `read_geocarb(filename)`. This function will return a data frame with the columns `year`, `co2.total`, `co2.atmos`, `alkalinity.ocean`, `delta.13C.ocean`, `delta.13C.atmos`, `carbonate.ocean`, `carbonate.weathering`, `silicate.weathering`, `total.weathering`, `carbon.burial`, `degassing.rate`, `temp.atmos`, and `temp.ocean`.

Chapter 8 Exercises

Exercise 8.1: Weathering as a function of CO_2

In the steady state, the rate of weathering must balance the rate of CO_2 degassing from the Earth, from volcanoes and deep-sea vents.

Run a simulation with `co2_spike` set to zero, and set the model to increase the degassing rate at time zero (i.e., set `degas_sim` to a higher value than `degas_spinup`).

a) Does an increase in CO_2 degassing drive atmospheric CO_2 up or down? How long does it take for CO_2 to stabilize after the degassing increases at time zero?

b) How can you see that the model balances weathering against CO_2 degassing (**Hint:** what variables would you graph with `ggplot`?)

c) Repeat this run with a range of degassing values for the simulation phase and make a table or a graph of the equilibrium CO_2 concentration versus the degassing rate.

   Does the weathering rate always balance the degassing rate when the CO_2 concentration stabilizes?

d) Plot the weathering as a function of atmospheric CO_2 concentration, using the data from the model runs you did in part (c).

Exercise 8.2: Effect of solar intensity on steady-state CO_2 concentration

The rate of weathering is a function of CO_2 concentration and sunlight, and increases when either of those variables increases. The sun used to be less intense than it is today.

Run GEOCARB with the spike set to zero, with the default values of 7.5 for both `degas_spinup` and `degas_sim`, and with the clock turned back 500 million years to when the sun was cooler than today.

What do you get for the steady state CO_2? How does this compare to what you get when you run GEOCARB for today's solar intensity? Explain why.

Exercise 8.3: The role of plants (Graduate students only)

The roots of plants accelerate weathering by two processes: First, as they grow, they open up the soil, making it more permeable to air and water. Second, the roots pump CO_2 down into the soil.

Run a simulation with no CO_2 spike at the transition and with no plants in the spinup, but with plants present in the simulation.

a) What happens to the rate of weathering when plants are introduced in year zero? Does it go up or down right after the transition? WHat happens later on?

b) What happens to atmospheric CO_2, and why?

c) When the CO_2 concentration changes, where does the carbon go?

Exercise from Chapter 10

Exercise 10.1: Long-term fate of fossil fuel CO_2

Use the GEOCARB model in its default configuration.

a) Run the model with no CO_2 spike at the transition. What happens to the weathering rates (Silicate, Carbonate, and Total) at the transition from spinup to simulation (i.e., year zero)?

b) Now set the CO_2 spike at the transition to 1000 GTon.

- What happens to the weathering at the transition? How does weathering change over time after the transition?
- How long does it take for CO_2 to roughly stabilize (stop changing)?

c) In the experiment from (b), how do the rates of total weathering and carbonate burial change over time?

- Plot what happens from shortly before the transition until 10,000 years afterward (**Hint:** you may want to add the following to your `ggplot` command: `xlim(NA,1E4)` to limit the range of the *x*-axis, or `scale_x_continuous(limits = c(NA,1E4), labels = comma))` if you also want to format the numbers on the *x*-axis with commas to indicate thousands and millions.)

  How do the two rates change? What do you think is happening to cause this?

- Now plot the carbon burial and total weathering for the range 1 million years to 2 million years. How do the two rates compare?