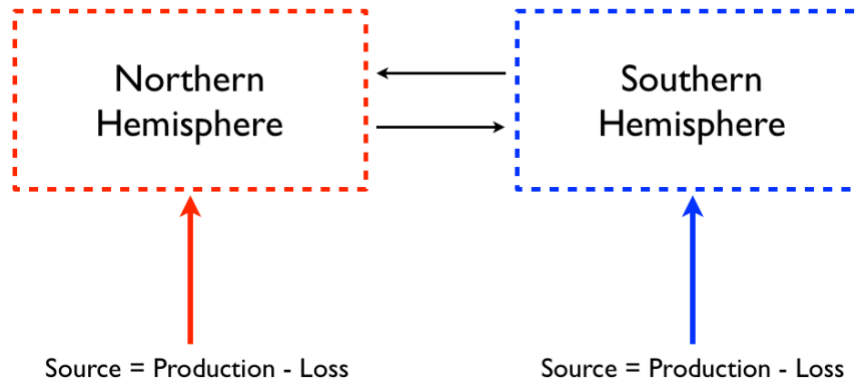


Problem Set 4 – Inverting for Sources and Sinks of Carbon

The assignment explores the principal observations about the contemporary carbon cycle, and uses an atmospheric 2-box mixing model to infer the distribution of carbon sinks over the last few decades.



The 2-box model for atmospheric mixing: S_n and S_s are the net fluxes into each hemisphere = production (sources) – loss (sinks). There are two parameters: τ , interhemispheric mixing time, and γ , the ratio of the surface hemispheric gradient to the column-averaged hemispheric gradient.

$$\frac{\partial M_n}{\partial t} = -\frac{M_n - M_s}{\tau} + S_n$$

$$\frac{\partial M_s}{\partial t} = \frac{M_n - M_s}{\tau} + S_s$$

$$S_s = P_s - L_s$$

$$S_n = P_n - L_n$$

We will use observations from Mauna Loa Observatory and South Pole Observatory to represent the mass of carbon in the Northern Hemisphere and Southern Hemisphere. γ , the ratio of surface measurement to the total column mass, will be multiplied by the observations to represent the total mass (M_s or M_n).

We will also use the fossil fuel emissions dataset from the first problem set to estimate emissions.

Files needed for PS4:

- Fossil Fuel data is from the Global Carbon Project (same data as from PS1):
<https://doi.org/10.5281/zenodo.5569235>

- Filename: GCB2021v34_MtCO2_flat.csv

- CO₂ Flask data is from ESRL: <http://www.esrl.noaa.gov/gmd/dv/data/>
 - Filename for MLO: co2_mlo_surface-flask_1_ccgg_month.txt
 - Filename for SPO: co2_spo_surface-flask_1_ccgg_month.txt
- Python code is in a Jupyter notebook called: PS4_Inversion.ipynb
 - Section 1 also loads Fossil Fuel and CO₂ flask data
 - ***You will define parameters at the top of Section 1***
 - Section 2 is a Forward integration of the 2-box model
 - Section 3 is the Inverse calculation
 - Section 4 has some additional calculations

The code performs a forward and inverse calculation of the sinks of CO₂ from 1981 to present. To start use $\tau = 1$ year, and $\gamma = 1$. These are the defaults that are set - you will vary these parameters for questions 3 and 4 by changing them at the top of Section 1. NOTE: In the forward integration of the model (Section 2 in the code) we are assuming that FF is 100% airborne.

The filenames for plots will be automatically named with your choice of tau and gamma, so you will get new saved figures each time you change a parameter.

-----PS 4 Questions-----

1. In Section (2) of the code – Forward Integration of a 2-Box Model. In the forward integration of the code (Section 2) we are assuming that Fossil Fuel remains 100% airborne. The plot created in this section compares the modeled surface hemispheric difference in CO₂ to the observed difference (MLO-SPO). What does the difference between the modeled result and the observations imply about the sinks (S_n , S_s , L_n and L_s)? Why is this a good or bad assumption? Answer should be qualitative and possibly include equations (not primarily numeric).
2. In Section (3) of the code – “Inverse calculation”. In the inverse calculation the code calculates the NH and SH sinks (L_n and L_s) from the observed MLO-SPO difference. See section 4 of the code for “additional calculations”. Note the following numbers (and come back to these in questions 3 and 4).
 - a. What is the cumulative total sink over this time period (in PgC)?
 - b. What is the Cumulative sink expressed as a percent of the cumulative FF emission over this time period? How does this compare to what we learned in PS1 about the airborne fraction?
 - c. What is the NH fraction of the total sink, averaged over the period? Does this number match your prior expectations?
3. An uncertainty in the determination of L_n and L_s is γ , an index of the vertical gradient of CO₂.
 - a. Why is there a vertical gradient in CO₂?
 - b. What is the NH fraction of the total sink, for $\gamma = 1.0, 1.2, 1.5, 2?$

- c. Why does NH sink vary as it does in (3b)?
4. The interhemispheric exchange time τ is determined using mid-latitude industrial emissions.
- a. What would a shift of emissions to China and India do to τ ?
 - b. What is the NH fraction of the total sink, for $\tau = 0.8, 1, 1.2, 1.5, 2$?
 - c. Can you guess why our estimate of NH fraction of the sink changes as it does in (4b)?