# 3.1 Global CO$_2$ Budget

Summary

This [Jupyter notebook](#) provides an analysis of global CO$_2$ emissions go by solving a mass balance.

Problem Statement

The total global emissons of CO$_2$ is estimated by the [Netherlands Environmental Assessment Agency](#) to be 34.5 billion metric tons from all sources, including fossil fuels, cement production, and land use changes. [As measured by NOAA](#), in recent years the atmospheric concentration of CO$_2$ is increasing at an annual rate of about 2.4 ppmv (parts per million by volume).
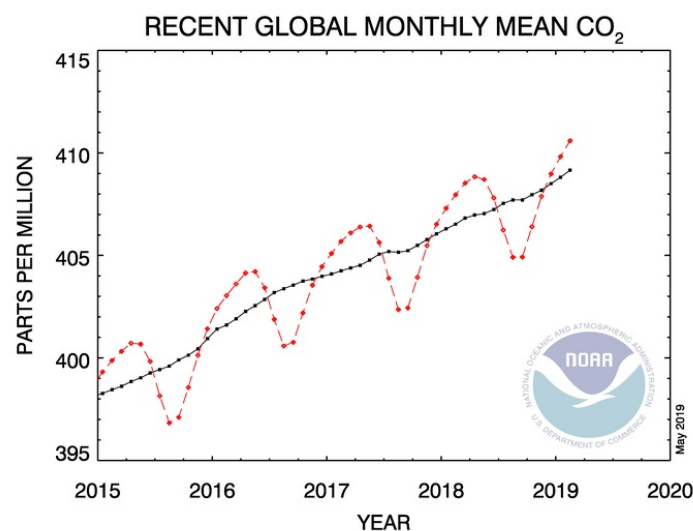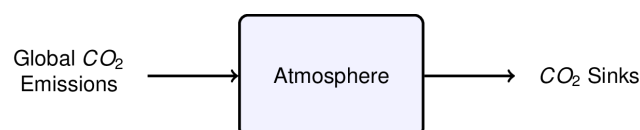

Assuming these numbers are accurate and that the atmosphere is well mixed, what fraction of global CO$_2$ emissions are being retained in the atmosphere?

Solution

This problem requires us to perform a material balance for CO$_2$ in the atmosphere. We'll perform the using a 10 step approach outlined in the textbook.

Step 1. Draw a diagram.

Step 2. Define the system of interest.

The system of interest is the global atmosphere which we assume is well mixed and of uniform composition.

Step 3. Choose components and define stream variables.

The chemical component to model is CO_2. The stream variables are the mass flowrates of CO2</sub> into and out of the atmosphere.

Step 4. Convert all units to consistent units of mass or moles.

This problem could be done on either a molar or mass basis. We'll arbitrarily choose to do this in mass units of kg/year. First we convert global emissions to kg/year.

In [ ]:

```
%matplotlib inline
from numpy import *
```

In [ ]:

```
mCO2_in = 34.5e9          # inflow, metric tonnes per year
mCO2_in = mCO2_in*1000     # inflow, kg per year
print("Global CO2 emissions = {:8.3g} kg/yr".format(mCO2_in))
```

Global CO2 emissions = 3.45e+13 kg/yr

The rate of accumulation is given as ppm by volume per year. For ideal gases, volume fraction is equivalent to mole fraction. We need to convert the mole fraction, which is the ratio of kg-moles of CO_2 to kg-moles of air, to mass fraction which has units of kg of CO_2 to kg of air per year.

In [ ]:

```
nCO2_accum = 2.4e-6                      # accumulation, kg-mol CO2/kg-mol air/yr

mwAir = 28.97                            # kg air/kg-mol air
mwCO2 = 44.01                            # kg CO2/kg-mol CO2

wCO2_accum = nCO2_accum*mwCO2/mwAir    # kg CO2/kg air/yr

print("Accumulation Rate of CO2 = {:8.3g} kg CO2/kg air".format(wCO2_accum))
```

Accumulation Rate of CO2 = 3.65e-06 kg CO2/kg air

Step 5. Define a basis.

The basis for the calculation are flows and change in one year. No additional work is required.

Step 6. Define system variables.

The system variable is the rate of accumulation of CO_2 in kg CO2/year. We need to convert from change in concentration per year to change in total mass per year. The first step is to estimate the total mass of air.

In [ ]:

```
# Earth Radius in meters
R = 6371000        # m

# Earth Area in square meters
A = 4*pi*R**2      # m**2

# Mass of the atmosphere in kg
g = 9.81           # N/kg
P = 101325         # N/m**2
mAir = A*P/g       # kg

print("Estimated mass of the atmosphere = {:8.3g} kg".format(mAir))
```

Estimated mass of the atmosphere = 5.27e+18 kg

To get the rate of change of total CO_2, multiply the total mass of by the rate of change of mass fraction of CO_2.

In [ ]:

```
mCO2_accum = wCO2_accum*mAir     # kg CO2/year

print("Change in CO2 = {:8.3g} kg CO2/year".format(mCO2_accum))
```

Change in CO2 = 1.92e+13 kg CO2/year

Step 7. List specifications

The inflow and rate of change of CO_2 are specified, and calculated above.

Step 8. Write material balance equations for each species.

$$\text{Accumulation} = \text{Inflow} - \text{Outflow} + \underbrace{\text{Generation}}_{=0} - \underbrace{\text{Consumption}}_{=0}$$

Step 9. Solve material balance equations.

$$\text{Outflow} = \text{Inflow} - \text{Accumulation}$$

In [ ]:

```
mCO2_out = mCO2_in - mCO2_accum

print("Global CO2 outflow = {:8.3g} kg CO2/yr".format(mCO2_out))
```

Global CO2 outflow = 1.53e+13 kg CO2/yr

Step 10. Check your work.

Fraction retained in the atmosphere

In [ ]:

```
fCO2 = mCO2_accum/mCO2_in
print("Fraction of CO2 retained in the atmosphere = {:<.2g} ".format(fCO2))
```

Fraction of CO2 retained in the atmosphere = 0.56

```
In [ ]:
```