Paper discussion Assignment #1 – Discussion of Sarmiento and Gruber (2002)

**Graded out of 15 points**

1) **Is the atmosphere presently at steady state with respect to CO2? (1pt)**

No. From figure 1 in the paper it is clear that the sources do not equal the sinks.

Sources: \(59.6 + 1.7 + 70.6 + 20 + 5.4 = 157.3 \text{ PgC/yr}\)

Sinks: \(0.2 + 60 + 1.9 + 70 + 21.9 = 154 \text{ PgC/yr}\)

Prior to anthropogenic CO2 emissions and deforestation the atmosphere was at steady state because the sources were equal to the sinks.

Sources: \(59.6 + 70.6 = 130.2 \text{ PgC/yr}\)

Sinks: \(0.2 + 60 + 70 = 130.2 \text{ PgC/yr}\)

2) **How many times is carbon recycled in marine biota before being exported? (5pts)**

Time for all surface ocean carbon to be converted to marine biota:

\[
\frac{918 \text{ PgC}}{50 \text{ PgC/yr}} = 18.36 \text{ yr}
\]

Time for all surface ocean carbon to be exported via marine biota export:

\[
\frac{918 \text{ PgC}}{11 \text{ PgC/yr}} = 83.45 \text{ yr}
\]

\[
\frac{83.45 \text{ yr}}{18.36 \text{ yr}} = 4.5
\]

Or

Turn over time of marine biota carbon: \(\frac{3 \text{ PgC}}{50 \text{ PgC/yr}} = 0.06 \text{ yr}\)

Export of carbon from marine biota reservoir: \(\frac{3 \text{ PgC}}{11 \text{ PgC/yr}} = 0.27 \text{ yr}\)

\[
\frac{0.27 \text{ yr}}{0.06 \text{ yr}} = 4.5
\]

The carbon is cycled through marine biota an average of 4.5 times before being exported.

3) **Why is the seasonal cycle of atm. CO2 controlled by land rather than the ocean? (2pts)**

Land plants undergo seasonal productivity during which their uptake of CO2 varies drastically. During the spring and summer there is a net CO2 draw down while in the fall and winter terrestrial productivity decreases and there is a net efflux of CO2 to the atmosphere. Since most terrestrial vegetation on earth is in the northern hemisphere the amplitude of this seasonal cycle is largest in the northern hemisphere atmospheric CO2 record.

In the ocean, productivity is equally prominent in both hemispheres but lacks a distinct seasonal cycle. Instead, biological productivity in the ocean is ongoing and seasonal weather changes don’t result in large swings in the net primary productivity. The ocean is very heterogeneous so there are regions where small seasonal signals are observable; however, in general the observable seasonal signals in ocean net primary production are much smaller than those observed on land. Seasonality does however influence the solubility of gases in seawater to a small extent (warmer = gases are less soluble, cooler = gases are more soluble).
The image below shows the seasonal comparison of net primary productivity. It is clear that the highest rates of net productivity are on land. The low seasonal variability in the ocean indicates that productivity in the ocean is less influenced by the changes in seasons than land plants.


Another interesting thing to consider is how gas solubility and biological productivity influence the exchange of CO$_2$ between the ocean and atmosphere. Consider the following simplified example.

**Boreal summer:**
- Net biological productivity removes CO$_2$ from the surface water
  - Surface water takes up atmospheric CO$_2$ to re-equilibrate
- Warming of the surface waters due to summer insolation results in lower gas solubility
  - Surface water outgases CO$_2$ to the atmosphere

**Boreal winter:**
- Net respiration allows for CO$_2$ to build up in the surface water
  - Surface water outgases CO$_2$ to the atmosphere
- Cooling of the surface waters due to low insolation during winter results in high gas solubility
  - Surface water takes up atmospheric CO$_2$ to re-equilibrate

In other words, the temperature dependence of gas solubility damps any small seasonal biological signals that are produced in the ocean.

4) **How much of the river flux of carbon comes from weathering?** (1pt) **Why is half from atm. (0.2) and half (0.2) from rocks?** (4pts)

Of the 0.8 PgC/yr that comes from rivers 0.4PgC/yr comes from weathering. The other 0.4PgC/yr comes from the transport of soil derived carbon. Half of the weathering derived carbon comes from the atmosphere and half comes from the weathered rocks. To understand why the carbon is partitioned this way consider the two major weathering pathways that include the weathering of carbonate and silicate rocks.
Carbonate rock weathering:
\[ \text{CaCO}_3 (s) + \text{CO}_2 (g) + \text{H}_2\text{O} = \text{Ca}^{2+} + 2\text{HCO}_3^- \]

Silicate mineral weathering (using K-feldspar as an example):
\[ \text{KA}_2\text{Si}_3\text{O}_8 (s) + \text{CO}_2 (g) + 5/2 \text{H}_2\text{O} = 1/2 \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 (s) + \text{K}^+ + \text{HCO}_3^- + 2\text{H}_4\text{SiO}_4^0 \]

(K-feldspar) (kaolinite)

During carbonate rock weathering one mole of atmospheric CO2 is sequestered for every one mole of rock that is weathered. Therefore, of the two moles of carbon that are carried away by the river in the form of bicarbonate (HCO3^-), one mole is derived from the rock and the other comes from the atmosphere.

In the case of silicate weathering the carbon that is carried away by the river in the form of bicarbonate is entirely from the atmosphere.

The ratio of silicate to carbonate weathering determines how much of the carbon transported by rivers originated from either the atmosphere or the carbonate rocks. Thus in order for the ratio of atmosphere to rock weathering to be 1:1 (0.2PgC/yr : 0.2PgC/yr) most of the weathering must be from carbonate rocks. Based on the table from Meybeck (1987) in your problem set the ratio of silicate to carbonate rock exposure is 82.8% / 15.8% = 5.2. This suggests that silicate rocks are weathered ~5 times more often than carbonate rocks in which case the weathering of CO2 from the atmosphere should be larger than the weathering flux from rocks as depicted in figure one from the Sarmiento and Gruber (2002) paper. However also recall from the problem set that your calculations indicate that carbonate rocks are weathered more than silicate rocks at a 4:1 ratio and thus most of the carbon that is transported via rivers is the result of carbonate rock weathering. Taking this into consideration the 1:1 ratio of atmospheric carbon to rock derived carbon is not a poor estimate in the Sarmiento and Gruber paper.

5) Why doesn’t atmospheric CO2 increase as fast as anthropogenic emissions? (2pts)

Approximately half of the anthropogenic CO2 emitted annually is partitioned between the ocean and terrestrial biosphere. As a result the rate of increase of CO2 in the atmosphere is about half of what would be predicted from emission/deforestation estimates alone.