Constraining the Potential Influence of the Ocean Biological Pump on Atmospheric pCO$_2$

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I. Introduction

- Particulate Organic Carbon (POC) flux to depth is the hallmark of the biological pump and critical to setting surface ocean pCO$_2$, $^{1,2,3}$ (Figure 1)
- Accurate estimation of the sensitivity of the biological pump to future climate change is critical to economic evaluations of the impacts of climate change on ecosystem services (e.g. fisheries).$^4$
- POC flux is commonly parameterized as power law with exponent $b=0.86$ (see Methods)$^5$ and is equivalent to increasing sinking speed with depth.$^6$
- A recent 3-D biogeochemical modeling study used $b$ range 0.4 - 1.4, which leads to range of equilibrium atmospheric pCO$_2$ of almost 100 ppm.$^7$
- A global data set of POC flux observations is available to directly test Martin curve in multiple provinces (Figure 2).$^8$

II. Methods

1. Power law (“Martin curve”) varied using exponent $b$ within range [0.4, 1.4] and $F(100)$ from a province-specific numerical simulation.$^9$ NADR province is shown.

\[
 F(z) = F(100) \left( \frac{z}{100} \right)^b 
\]

- $z$ : Depth in meter (m)
- $F(z)$ : POC flux at depth $z$
- $F(100)$ : POC flux at 100m
- $b$ : Attenuation parameter

2. Retrieved normalized bias ($B^*$), which quantifies how well the Martin curve captures the observations.

\[
 B^* = \frac{\text{Observe Standard Deviation}}{\text{Bias}} 
\]

Bias is calculated using in-situ observations in the midnight zone (see Figure 1) and Martin with varying $b$. Selected $b$ values where $B^*$ is within $[-1,1]$.$^{10}$

3. Atmospheric pCO$_2$ as a function of $b$ is from the global 3-D biogeochemical modeling study of Kwon et al. [2009] relative to Martin's composite $b=0.86$ (shown in red).

Steps 1-3 are performed for provinces where there is sufficient data at depth, 11 out of 54 provinces (Figure 2). Global range of $b$ and $\Delta$ pCO$_2$ quantified as the interquartile range of all 11 provinces (Figure 3).

III. Results / Conclusion

- Range of Martin's $b$ constrained to in-situ observations in the midnight zone, where long-term carbon sequestration occurs, is [0.70, 0.98]
- Limited range of $b$ has the capacity to change atmospheric pCO$_2$ by only a few tens of parts per million, 0.4 ppm to 0.12 ppm.

Data-constrained $b$ range suggests atmospheric pCO$_2$ is not strongly impacted by uncertainty in the biological carbon pump. Transport of organic matter to depth is most certainly critical to the function of ocean ecosystems.

References:

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**Figure 1.** Schematic depicting the basic mechanism of the biological pump: Carbon dioxide dissolved in the surface ocean is converted to dissolved inorganic carbon (DIC) which is photosynthetically converted to organic carbon. Particulate organic carbon (POC) sinking out of the surface ocean is remineralized at depth, sequestering carbon from the atmosphere.

**Figure 2.** POC flux observations overlain with Longhurst provinces. Blue dot indicates sites of moored sediment traps and thorium-234 depolymerization (available at doi:10.1594/PANGAEA.855600). 11 out of 54 provinces are considered, where there is a sufficient percentage of observations at depth (indicated by color).

**Figure 3.** Range of $b$ values for each province and change in atmospheric pCO$_2$ relative to Martin et al. [1987] composite $b$ value of 0.86 (red line). The dotted lines are the 25th and 75th percentiles (interquartile range) and the solid black line is the median.