Does the Iron Cycle Regulate Atmospheric CO$_2$?

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- What regulates atmospheric CO$_2$ on glacial-interglacial timescales?
- Role of ocean biology?
- Does the iron cycle control atmospheric CO$_2$?
The Global Carbon Cycle

70 times more carbon in ocean than atmosphere

~3000 Pg of ocean carbon storage due to biological processes:

Small change in ocean biological storage could lead to big change in atmosphere.

What controls the efficiency of biological pumps?

<table>
<thead>
<tr>
<th></th>
<th>atmhos</th>
<th>600 Pg C</th>
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<tbody>
<tr>
<td>ocean</td>
<td>38,000 Pg C</td>
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Outline

• Biological storage of carbon in the oceans
• Iron as control on ocean biological activity
• Iron cycle processes
• Modeling the ocean iron and carbon cycles
Photosynthesis and Respiration

$$106 \text{ CO}_2 + 16 \text{ NO}_3^- + \text{H}_2\text{PO}_4^- + 122 \text{ H}_2\text{O} + X \text{ h} \text{v} \leftrightarrow C_{106}H_{263}O_{110}N_{16}P + 138 \text{ O}_2$$

Observed flux of sinking particulate organic carbon

Martin et al. (1987)
Biological activity moves nutrients (phosphate) and carbon downwards in the water column

Deep ocean carbon enriched due to “biological pump” — lowers atmospheric CO$_2$

**Classical view:**
Availability of phosphate (or nitrate) at surface limits biological productivity and biological storage of carbon in deep ocean
Primary productivity:
Rate of formation of organic carbon from remote observations
(Behrenfeld and Falkowski, 1997)

Upwelling brings phosphate to surface fuelling production of organic matter and sinking flux of organic carbon
Primary productivity:
Rate of formation of organic carbon from remote observations
(Behrenfeld and Falkowski, 1997)

Why doesn’t ecosystem utilize all surface phosphate?
- Biological storage of carbon not at full efficiency
Martin and Fitzwater (1988):

- Productivity limited by availability of micro-nutrient **iron**
- Shipboard iron enrichment incubation experiments
Fig. 1 Chlorophyll concentrations versus experimental day (a) in control (no added Fe) and experimental bottles with 1 nmol Fe, 5 nmol Fe and 10 nmol Fe added per kg. The data shown for day 6* represent a second set of replicates that were opened only upon the completion of the experiment. Nitrate (b) and phosphate (c) concentrations versus day are also shown. Because of the unintentional addition of 3 μmol NO₃⁻ kg⁻¹, the data for the experimental bottles with 10 nmol Fe plus 1.0 nmol Mn and 0.1 nmol Co per kg are not included in this figure (see Table 1). Bottles were placed in three plastic bags and maintained in an all plastic deck-top incubator. Light levels were ~20% of those at the sea surface; temperatures were kept at ~14 °C via running seawater.
Open ocean fertilization experiments

Addition of iron leads to
● enhanced primary production
● enhanced export of sinking particulate organic matter (some experiments)

SOIREE
What regulates ocean iron concentration?

- low solubility
- scavenging onto sinking particles
- complexation with organic ligands protects from scavenging
- aeolian (wind-borne) dust source

Ocean iron cycle processes
A massive sandstorm blowing off the northwest African desert has blanketed hundreds of thousands of square miles of the eastern Atlantic Ocean with a dense cloud of Saharan sand. The massive nature of this particular storm was first seen in this SeaWIFS image acquired on Saturday, 28 February 2000 when it reached over 1000 miles into the Atlantic. These storms and the rising warm air can lift dust 15,000 feet or so above the African deserts and then out across the Atlantic, many times reaching as far as the Caribbean where they often require the local weather services to issue air pollution alerts as was recently the case in San Juan, Puerto Rico. Recent studies by the U.S.G.S. (http://cabinet.eace.gov/african_dust) have linked the decline of the coral reefs in the Caribbean to the increasing frequency and intensity of Saharan Dust events. Additionally, other studies suggest that Saharan Dust may play a role in determining the frequency and intensity of hurricanes formed in the eastern Atlantic Ocean (http://www.thirdworld.org/rare.html).

Provided by the SeaWIFS Project, NASA/GSFC and ORBIMAGE.
Aeolian iron deposition

Mahowald et al. (2003)
Martin (1990): The Iron Hypothesis

- increased dust/iron supply in dry, dusty glacial climate
- relieves iron limitation
- enhances biological pump
- reduces atmospheric $\text{CO}_2$

Ice core record

![Graph showing atmospheric CO$_2$ and dust flux over time.](image)
Could a change in the atmospheric source of iron really change atmospheric pCO$_2$ by 100 ppmv?

We can use models of ocean circulation and biogeochemical cycles to explore this question:

Mathematical description of key processes and interactions: Circulation and biogeochemistry

- Does model reproduce key features of observed system?
- Can it help us to understand observations?
- What are sensitivities of system?
Observed surface total dissolved iron

- Compiled by Parekh et al. (2005)
Modelled Iron Distribution - surface

- $L_T \sim 1$ nM
- $-\log(\beta) \sim 11$
- $K_{sc} \sim 1$ year$^{-1}$

- Parekh et al (2005)
Model suggests...

(Parekh et al., 2005; Dutkiewicz et al., 2005; Ito et al., 2005)

- “Productivity belt” where both iron and phosphate are available in optimal ratio

- 90% of iron source to surface southern ocean is through upwelling
  - *complexation with organic ligands controls productivity*
What happens to atmospheric $pCO_2$ if we change the atmospheric supply of dust/iron in the model?

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Dead ocean''
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more iron --->

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Last Glacial Max''
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Models suggest that increasing atmospheric supply to Last Glacial Maximum levels only reduces pCO2 by about ~10ppmv

- Upwelling concentration of iron controls productivity
- Upwelling concentration controlled by availability of organic ligand

But what controls availability of ligand?
- Need better understanding of nature and cycle of organic complexing molecules