Ocean Biogeochemistry in the Earth System

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Global mean surface temperature has increased more than 0.5°C since the beginning of the 20th century, with this warming likely being the largest during any century over the past 1,000 years for the Northern hemisphere.
An increasing body of observations of climactic and other changes in physical and ecological systems gives a collective picture of a warming world.

Global temperature will rise from 1.4-5.8°C over this century unless greenhouse gas emissions are greatly reduced.
There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.

CO₂ Concentration in Ice Cores and Atmospheric CO₂ Projection for Next 100 Years

- Vostok Record
- Law Dome Record
- Mauna Loa Record
- IPCC IS92a Scenario

Source: C. D. Keeling and T. P. Whorf; Etheridge et al.; Barnola et al.; (PAGES/IGBP); IPCC
Preindustrial CO2: maximum strength bio pump: 160 ppm

Oceanic Primary Production: Sept. 97 – Aug. 98
INVERSE METHODOLOGY
Basis: Conservation of “material”

1. Advective flux across internal boundaries (unknown)
2. Turbulent mixing across internal boundaries (unknown)
3. Within box:
   - Radioactive decay (known)
   - Biochemical processes (unknown)
4. Flux across external boundaries (known)
This leads to inverting

\[ Ax = b \]

Under constraints

\[ Gx \geq H \]

Where \( A=(910, 630) \) is one

*Badly ill-conditioned, sparse unstructured matrix . . .*

Having lost sight of our objective,

we redoubled our effort . . .
Remembrance of Things Past

<table>
<thead>
<tr>
<th></th>
<th>1970s</th>
<th></th>
<th>1980s</th>
<th>1990s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric increase</td>
<td>$3 \pm 0.1$</td>
<td>Emissions (fossil fuel, cement)</td>
<td>$5 \pm 0.3$</td>
<td></td>
</tr>
<tr>
<td>Ocean-atmosphere flux</td>
<td>$-2.5 \pm 0.3$</td>
<td>Land-atmosphere flux</td>
<td>$2 \pm 3??$</td>
<td></td>
</tr>
</tbody>
</table>

*partitioned as follows

<table>
<thead>
<tr>
<th></th>
<th>1980s</th>
<th>1990s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land-use change</td>
<td>1.7 (0.6 to 2.5)</td>
<td>N/A</td>
</tr>
<tr>
<td>Residual terrestrial sink</td>
<td>-1.9 (-3.8 to 0.3)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Source: IPCC Third Assessment Report
620 ARGO Floats, as of January 2003

MODIS Ocean Chlorophyll
Orbiting Carbon Observatory - JPL
The Carbon System

The source and sinks and controlling processes will only be determined within an integrated approach where point-wise \textit{in situ} surface measurements can be scaled up using global satellite datasets and models, and then constrained and verified by atmospheric CO$_2$ concentration measurements.
Sea Ice

Surface T

Albedo

Source: IPCC Third Assessment Report
An example of the ocean’s impact of climate change: the switching on and off of the Atlantic thermohaline circulation (THC) causing three different modes of planetary operation during glacial times.

Seasonal fluxes of total N predicted by a non-linear statistical model. A geospecific, aquatic transport model will be used to predict coupled water, sediment, C, and N fluxes through individual gridded river networks at 0.1° (long/lat) resolution as part of this proposed work.

Which consequences have changes in species composition?

- **Chaetoceros costatus** (Diatom)
- **Emiliania huxlei** (Coccolithophorids)
- **Distephanus speculum** (Silicoflagellate)
- **Trichodesmium** (Cyanobacterium)
Atmosphere (box) \( h_a \)

Surface ocean (box) \( h_m \)

Intermediate Ocean (diffusive-advective) \( h_i \)

Deep ocean (box) \( h_d \)

“Pipeline”

Human Activity
- Industry, Agriculture, Fishing

Atmospheric Composition

Chemistry

Biology
- Lower and Higher Trophic Levels

Physical Forcing
- Transport processes and climate change

Source: K. Locke, IGBP/SCOR Ocean Futures Document