Towards a Deep Ocean Observing Strategy

Setting the stage

Ocean Biogeochemistry

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At a global level.

- Summarize state of knowledge,
- What are the key phenomenon?
- Key space and time scales and where do they happen? (Global/Decadal)
"Biogeochemistry":
- Inorganic carbon chemistry, and (chemical) reactants and products resulting from biological processes involving carbon
- Inferring biological processes through chemistry

- Ocean biogeochemistry is integral component of the global carbon cycle
- Separated in natural and anthropogenic component

Sarmiento and Gruber Physics Today 2002
A simple accounting of deep ocean carbon

Ocean > 200 m

≈ 80 % anthropogenic carbon storage (≈130 Pg C)
  Atmospheric CO₂ changed by 250 Pg C or 40 % (280-400 ppm); Deep ocean inventory changed by 0.3 %
≈ 2 Pg C/yr increase from anthropogenic carbon
≈ 9 Pg C/yr addition in form of PC (PIC&POC)
≈ 2 Pg C/yr addition in form of DOC
≈ 11 Pg C/yr return to the surface as DIC
≈ 0.2 Pg C/yr loss to sediments

In Steady State: Turnover time 400 -4000 years

Red: anthropogenic carbon  Black : “Natural” carbon
Processes: Physical

(impact all ocean properties)

Large scale

Local scale

- Mixing
- Eddy processes

C. Whalen, UCSD
A canonical view of vertical biological particulate transport (diapycnal) transport

The Martin Curve (OOC: Open Ocean composite):

\[ F_{PC} = 1.53 \left( \frac{z}{100} \right)^{-0.858} \]

The change with depth is dissolution

Decrease in:
- POC
- \(O_2\)
- pH
- DOC

Corresponding increase in:
- Inorganic carbon, DIC / TCO\(_2\)
- Alkalinity
- pCO\(_2\)
- nutrients

Fig. 5. Open ocean composite (OOC) fluxes for C using the means of replicates at various depths from Stas 2, 4, 5, II, III and NPEC: \( F = 1.53(\frac{z}{100})^{-0.858} \); \( r^2 = 0.81; n = 48 \).
Impact of transport and particulate fluxes

1. biogeochemistry

**Key et al., GLODAP (BGC 2004)**

- Nutrients as TCO$_2$
- O$_2$ inverse
- Redfield:
  - P:N:C:-O$_2$ = 1: 16±1: 117±14 : 170±10

Top 1500 m, particle fluxes  > 3000 m transport and oxidation
2. Anthropogenic carbon and transient tracers
   Not influenced by biogeochemistry?

Impact of transport and particulate fluxes

Key et al., GLODAP (BGC 2004)
Impact of transport and particulate fluxes

Oxygen Minimum Zones ≈200-1000 m

- Expansion due to changes in ventilation and (possibly) biogeochemistry
- Impact on biogeochemistry (oxygen and nitrogen cycles)
- Concern for biology (from microbes to fishes)

Oxygen concentration at 400 m

Stramma et al. Science 2008
Impact of transport and particulate fluxes

Calcium carbonate saturation states

- Expansion due to changes in ventilation and $C_{\text{anthro}}$
- Impact on biogeochemistry (Carbon cycle, $T\text{Alk}$)
- Concern for biology (for shelled organisms)

**Figure 3.** Spatial distributions of aragonite saturation state ($\Omega_{\text{arag}}$) at depth levels of (a) 50 m, (b) 100 m, (c) 200 m, and (d) 500 m in the global oceans. Colors show gridded values based on Data Interpolating Variational Analysis (DIVA). Black dots show the sampling stations.

**Figure 5.** Spatial distributions of aragonite saturation state ($\Omega_{\text{arag}}$) at depth levels of (a) 1000 m, (b) 2000 m, (c) 3000 m, and (d) 4000 m in the global oceans. Colors show gridded values based on Data Interpolating Variational Analysis (DIVA). Black dots show the sampling stations.

Jiang et al. GBC, 2015
Impact of transport and particulate fluxes

Beyond the Martin Curve, Transfer efficiencies vary by region

Deep ocean nutrients imply large latitudinal variation in particle transfer efficiency,

Weber et al. PNAS 2016
"Whether the size of this large carbon pool will change in a warmer, more stratified ocean will determine whether the refractory organic carbon reservoir will be an important future carbon sink or source."

Impact of transport and particulate fluxes

Anthropogenic CO$_2$:
- Stovepipes to the deep
- The importance of outcropping

Column inventory of anthropogenic CO$_2$ below 2000 m (mol m$^{-2}$)

*based on Sabine et al. (2004)*
Essential Ocean Variables (EOVs) for Biogeochemistry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EOV</th>
<th>DOOS EOV</th>
</tr>
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<tbody>
<tr>
<td>Oxygen</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Inorganic Macro Nutrients</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Carbonate System</td>
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<td>X</td>
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<tr>
<td>Transient Tracers</td>
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<td>X</td>
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<tr>
<td>Suspended Particulates</td>
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<td>X</td>
</tr>
<tr>
<td>Nitrous Oxide</td>
<td>X</td>
<td>X &lt;2000 m</td>
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<tr>
<td>Stable Carbon Isotopes</td>
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<td>X</td>
</tr>
<tr>
<td>Dissolved Organic Carbon</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>$^{14}$C DOC</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Particulate tracers (Th)</td>
<td></td>
<td>X</td>
</tr>
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</table>

- All EOVs for biogeochemistry are applicable for DOOS EOVs
Tools of the trade (physics & biogeochemistry):

1. “old fashioned” deep water hydrography GO-SHIP
   - Climate quality measurement of tier-1 parameters
   - New parameters (isotopes, organic speciation)
   - New methodologies and analytical techniques

2. New platforms
   - Moorings & crawlers
   - Profiling floats
   - Gliders

3. New autonomous instruments
   - O₂
   - pH
   - NO₃
   - pCO₂

4. Combinations thereof
Questions for DOOS Biogeochemistry

Overriding issue for biogeochemistry:

The Biogeochemistry of the Deep Ocean is Changing

- Why? (forcing)
- How? (processes)
- Impacts (?) (response)

Broad questions for biogeochemistry:

1. **Magnitude**: How much anthropogenic carbon is stored in the deep ocean?
2. **Trends**: What are the trends in storage and remineralization of carbon and nutrients?
3. **Processes**: What are the mechanisms of changing OC and O$_2$ (biology vs physics)?
4. **Impacts**: How are changing inventories and processes changing deep ecosystems?
5. **Impacts**: Biogeochemical feedbacks (e.g. N$_2$O cycle)?
“I don’t know why I don’t care about the bottom of the ocean, but I don’t.”

Slide adapted from Kristina Gjerde, IUCN; cartoon from New Yorker magazine