CBGC.v1 Marine Biogeochemistry

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Evaluation of ocean and sea ice biogeochemistry

Paper Outline:
- Analysis of the 1850 CONTROL and the BDRD historical MPAS-O/SI BGC
- Special emphasis on the polar regions, validating new sea ice bgc model and interactions with the ocean system, identifying interesting model behavior
- Contrast Arctic vs. Southern Ocean
- Key processes in the marine carbon cycle:
  - Primary Production (inorganic C -> organic C) limitation factors, nutrient sources (rivers)
  - Sequestration (POC flux to the deep ocean)
  - Remineralization ($O_2$ minimum zones)
How do we validate submodule behavior in a component in a fully coupled modeling context?

Right behavior for the right reasons
How do we validate submodule behavior in a component in a fully coupled modeling context?

Right behavior for the right reasons

Wrong behavior for the right reasons
Metrics to assess the quality of the polar climate state for sea ice biogeochemistry

Sea ice (concentration, thickness, snow), ocean (nutrients), atmospheric (shortwave) properties

Define a “bound of maximal ice algal growth rate”:
Combines mean annual incident shortwave with upper ocean nitrate and silicate concentrations to estimate the maximum mean ice algal growth rate in ice covered regions.

- contrast observations based/model based
- No information on sea ice thickness, meltponds, snow cover, ice bgc
Based on Observation (Present Day)

Maximal Algal Growth Bound (obs. based)

![Map based on observation showing algal growth bound.]

Model Based (1850 CBGC Control)

Maximal Algal Growth Bound (model based)

![Map based on model showing algal growth bound.]

*No information on sea ice properties (except conc > 15%) or ice biogeochemistry*
Based on Observation (Present Day)

Fraction of year max ice algal growth bound is nitrate limited

In reality and in the model, snow and ice thickness will contribute to light limitation. Sea ice growth and melt rates contribute to nutrient limitation.
Inconsistencies in riverine fluxes of fresh water and nutrients. Path/strength of Pacific water?

Maximal Algal Growth Bound (obs. based)

Maximal Algal Growth Bound (model based)
All is not lost…. Model PP and Max Growth are highly correlated ($r = 0.74$)
Estimate for total Arctic ocean primary production is \( \sim 135 \text{TgC/y} \) (Macdonald et al. 2010)

Estimates for total Arctic Ice Algal Primary production is 23-170 TgC/y (Arrigo 2013)
Regression Estimate (R.E.)

CNTL Estimate
Tot PP 5-7 TgC/y

Regression Estimate (R.E.)
Tot PP = 60.7 TgC/y

Sea Ice PP (5 yr running avg)
Ocean nutrients are plentiful, light is essentially the only limiting factor + ice conc.
No correlation \( (r = 0.05) \)

**Mean Annual Ice Primary Production (gC/m²)**

- Obs estimates 3.6-456 TgC/y (Arrigo 2013)
- Tot PP = ~15 TgC/y

**Maximal Algal Growth Bound (model based)**
Observations

ASPeCT Ice Cores Integrated Chl-a (mg/m^2)
Globally integrated air-sea CO$_2$ exchange (Gt-C/year)

Positive into atmosphere

Model year (relative to start of production)

Globally integrated primary production (Gt-C/year)

Model year (relative to start of production)
\( \log_{10}(\text{primary production}) \) (mg-C/m\(^2\)/day)

Low resolution

High resolution

Observational estimate
Dissolved Oxygen at 640m (mmol/m$^3$)

- Too extensive Oxygen Minimum Zones (OMZs)
  - Atlantic should not be anoxic
  - Partly due to poor representation of Antarctic Intermediate Water (AAIW)
  - Affects denitrification and remineralization
- Southern ocean deficit due to unrealistically shallow mixed layers
Biotic vs Abiotic effects

- 2 kinds of DIC in BEC => DIC and DIC\textsubscript{alt}
- For non-BPRP cases (all of ours), they are redundant
- Instead, assign ‘B’ CO\textsubscript{2} to DIC, ‘R’ CO\textsubscript{2} to DIC\textsubscript{alt}
- Split ocn-atm flux into 2 parts: Biological and Solubility
  - Not exact, but a good approximation
  - \( F = B(T, CO_2, N_{dep}) + S(T, CO_2) \)
    - No pH effects on biology
    - Climatological \( N_{dep} \)
- In addition, turn off ecodynamics for DIC\textsubscript{alt} except for BCRD, BDRC
CTRL CO₂ flux (Gt-C/year) (positive into atmosphere)
<table>
<thead>
<tr>
<th></th>
<th>DIC</th>
<th>DIC\textsubscript{alt}</th>
<th>DIC - DIC\textsubscript{alt}</th>
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<tbody>
<tr>
<td>CTRL</td>
<td>B(T\textsubscript{CTRL}) + S(T\textsubscript{CTRL}, CO\textsubscript{2}\textsubscript{CTRL})</td>
<td>S(T\textsubscript{CTRL}, CO\textsubscript{2}\textsubscript{CTRL})</td>
<td>B(T\textsubscript{CTRL})</td>
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<tr>
<td>BCRC</td>
<td>B(T\textsubscript{RC}) + S(T\textsubscript{RC}, CO\textsubscript{2}\textsubscript{CTRL})</td>
<td>S(T\textsubscript{RC}, CO\textsubscript{2}\textsubscript{CTRL})</td>
<td>B(T\textsubscript{RC})</td>
</tr>
<tr>
<td>BDRD</td>
<td>B(T\textsubscript{RD}) + S(T\textsubscript{RD}, CO\textsubscript{2}\textsubscript{RD})</td>
<td>S(T\textsubscript{RD}, CO\textsubscript{2}\textsubscript{RD})</td>
<td>B(T\textsubscript{RD})</td>
</tr>
<tr>
<td>BCRD</td>
<td>B(T\textsubscript{RD}) + S(T\textsubscript{RD}, CO\textsubscript{2}\textsubscript{CTRL})</td>
<td>B(T\textsubscript{RD}) + S(T\textsubscript{RD}, CO\textsubscript{2}\textsubscript{RD})</td>
<td>-(S(T\textsubscript{RD}, CO\textsubscript{2}\textsubscript{RD}) - S(T\textsubscript{RD}, CO\textsubscript{2}\textsubscript{CTRL}))</td>
</tr>
<tr>
<td>BDRC</td>
<td>B(T\textsubscript{RC}) + S(T\textsubscript{RC}, CO\textsubscript{2}\textsubscript{RD})</td>
<td>B(T\textsubscript{RC}) + S(T\textsubscript{RC}, CO\textsubscript{2}\textsubscript{CTRL})</td>
<td>S(T\textsubscript{RC}, CO\textsubscript{2}\textsubscript{RD}) - S(T\textsubscript{RC}, CO\textsubscript{2}\textsubscript{CTRL})</td>
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Isolate S(T\textsubscript{RD}, CO\textsubscript{2}\textsubscript{CTRL}):  
Change in Solubility component due to T increase => (DIC\textsubscript{BCRD} - (DIC - DIC\textsubscript{alt})\textsubscript{BDRD})

No S(T\textsubscript{CTRL}, CO\textsubscript{2}\textsubscript{RD}), so compute S(T\textsubscript{RC}, CO\textsubscript{2}\textsubscript{RD}):  
Change in Solubility component due to CO\textsubscript{2} increase => (DIC\textsubscript{alt})\textsubscript{BCRC} + (DIC - DIC\textsubscript{alt})\textsubscript{BDRC}
Change in Solubility component of CO₂ flux due to T increase (Gt-C/year)
Change in Solubility component of CO₂ flux due to CO₂ increase (Gt-C/year)