Introduction to (a corner of) Marine Ecosystem Modeling

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Outline of Presentation

• What is an NPZD model?
• Plankton Functional Groups (PFTs)
• CCSM BEC model
• Model Validation
What is an NPZD model?

N  Nutrient
   nitrate, ammonium,
   phosphate, silicate, iron, etc.
P  Phytoplankton
   photosynthesizers
Z  Zooplankton
   grazers
D  Detritus

Canonical Example
Fasham, Ducklow, McKelvie,

Many more variations are used...

Fasham model diagram from www.gotm.net
Simple NPZ Model

\[
\frac{dP}{dt} = \mu_0 \left( \frac{N}{k_N + N} \right) \left( 1 - e^{\alpha E/\mu_0} \right) P - g \left( \frac{P}{k_p + P} \right) Z - m_p P
\]

Nutrient limitation Light limitation Grazing Mortality

\[
\frac{dZ}{dt} = ag \left( \frac{P}{k_p + P} \right) Z - m_z Z
\]

\[
\frac{dN}{dt} = -\mu_0 \left( \frac{N}{k_N + N} \right) \left( 1 - e^{\alpha E/\mu_0} \right) P + (1 - a) g \left( \frac{P}{k_p + P} \right) Z + m_p P + m_z Z
\]

• Three coupled ordinary differential equations
• Mass conservation
How do you estimate parameters and functional forms?

- Laboratory & field incubations
  - P-I curves
  - Nutrient uptake curves
- Tune/Optimize against field data
- Previous Models
Plankton Functional Groups (PFTs)

• Categorize plankton species by how they function and use representative groups

  – Explicit biogeochemical role
  – Biomass and productivity controlled by distinct physiological, environmental, or nutrient requirements
  – Behavior has distinct effect on other PFTs
  – Quantitative importance in some region of the ocean
# MAREMIP Models – Stage 0

<table>
<thead>
<tr>
<th>Model: Property:</th>
<th>PlankTOM5</th>
<th>PISCES</th>
<th>NEMURO</th>
<th>CCSM-BEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>pPFTs (phyto)</td>
<td>3: Diatoms*&lt;br&gt;Coccolithophores**&lt;br&gt;Nanophytoplankton^</td>
<td>2: Diatoms&lt;br&gt;Nanophytoplankton</td>
<td>2: Small phyto^&lt;br&gt;Large phyto*</td>
<td>3: Diatoms&lt;br&gt;Nanophytoplankton&lt;br&gt;Diazotrophs</td>
</tr>
<tr>
<td>zPFTs (zoo)</td>
<td>2: Microzooplankton^^&lt;br&gt;Mesozooplankton</td>
<td>2: Microzooplankton&lt;br&gt;Mesozooplankton</td>
<td>3: Small zoo (micro)&lt;br&gt;Large zoo (meso)&lt;br&gt;Predatory zoo (macro)</td>
<td>1: Generic zoo</td>
</tr>
<tr>
<td>Physics</td>
<td>NEMO</td>
<td>NEMO</td>
<td>COCO</td>
<td>CCSM</td>
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<tr>
<td>Who</td>
<td>UEA</td>
<td>IPSL</td>
<td>JAMSTEC/Hokkaido</td>
<td>Woods Hole</td>
</tr>
</tbody>
</table>

* silicifiers; ** calcifiers, ^ mixed phytoplankton, ^^ protozooplankton
Skill & Portability in 12 Different NPZD models
Friedrichs et al., JGR-Oceans, 2007.

(b) Simple models do just as well as more complex models when tuned for specific sites.
(c) More complex models do better at multiple sites with single parameter sets.
(d) More complex models perform better at different sites when tuned for one site.
CCSM BEC model

Doney et al. (J. Mar. Systems, 2009)

Moore, Doney, Lindsay, Global Biogeochemical Cycles, 2004.
Primary Features of BEC Model

- Fixed C:N:P ratios in plankton (24 tracers)
- Variable Fe:C, Si:C, Chl:C ratios
- Implicit coccolithophores
Original BEC

Improved BEC
sediment Fe source
Fe scavenging
Fig. 10. Binned iron concentration values from the observations (thickest line), the New BEC simulation (medium line), and the Old BEC simulation (thin line) over depth ranges of 0–103 m (A), 103–502 m (B), and from greater than 502 m (C).
Model Validation
Examples of Data Sets

- Macronutrients (PO$_4$, NO$_3$, SiO$_3$) from WOA
- pCO$_2$ and CO$_2$ Flux assembled by Takahashi
- Surface Chl measured by satellite
- Productivity estimated from satellite
- JGOFS study sites
- HOTS & BATS timeseries
Doney et al. (J. Mar. Systems, 2009)
Air-sea CO$_2$ Flux

Doney et al. (Deep-Sea Res. II, 2009)
Taylor Diagram

Global Domain spatial-annual

Correlation

MLD
pCO₂
SiO₃
PO₄
NO₃
O₂
O₂ Flux
CO₂ Flux
SST
Phyto Growth Rate
Phyto Carbon (log)
P. Production (log)
Chlorophyll (log)
Skill assessment for coupled biological/physical models of marine systems

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