Marine Ecosystem and Biogeochemistry in the Community Earth System Model

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The Biogeochemical Elemental Cycling (BEC) model has not changed much for the implementation in the CESM from CCSM 3. It is an ecosystem and biogeochemical module that runs within the CCSM POP2 ocean circulation model.

**Key Model Components:**
- Four phytoplankton functional groups,
- One adaptive zooplankton class,
- Key limiting nutrients (N, P, Fe, Si), plus C, O, and alkalinity
- Dissolved Organic Matter
- Sinking Particulates (Organic, bSi, CaCO$_3$, Dust)

Includes atmospheric deposition of nitrogen and iron.
### Biogeochemical Elemental Cycling (BEC) Model

<table>
<thead>
<tr>
<th>Small Phytoplankton</th>
<th>Diatoms</th>
<th>Diazotrophs</th>
</tr>
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<tbody>
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<td>C, Chl, Fe, CaCO₃</td>
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- **Dissolved Organic Matter**
  - C, N, P, Fe

- **Sinking Particulates**
  - C, Fe, Si, CaCO₃, Dust

- **Diazotrophs**
  - C, Chl, Fe

- **Small Phytoplankton**
  - C, Chl, Fe, CaCO₃

- **Diatoms**
  - C, Chl, Fe, Si

- **Zooplankton**
  - C

- **Dissolved Organic Matter**
  - C, N, P, Fe

- **Sinking Particulates**
  - C, Fe, Si, CaCO₃, Dust

- **Diazotrophs**
  - C, Chl, Fe

- **Nitrate**
- **Ammonium**
- **Phosphate**
- **Iron**
- **Silicate**
- **Oxygen**
- **DIC**
- **Alkalinity**

**CCSM4 POP2 ocean circulation model, ~1 degree resolution with 60 vertical levels.**
CESM Ocean Ecosystem Component

Many aspects of the CESM BEC have been documented previously.

Basic Ecosystem and Biogeochemistry
  (Doney et al., 1996; 2001; Moore et al., 2002; 2004)

Water Column Denitrification  (Moore and Doney, 2007)

Sedimentary Iron Source  (Moore and Braucher, 2008)

Atmospheric Nutrient Deposition
  (Krishnamurthy et al., 2007; 2009; 2010; Doney et al., 2007)

Diazotroph ability to take up inorganic nitrogen
  (previously all N from nitrogen fixation)
A) Diatom Growth Limitation

Nitrogen 56.43%, Iron 38.88%, Silica 2.038%, Phosphorus 2.637%
Replete 0.009%

- Nitrogen
- Iron
- Phosphorus
- Silicon
- Light
- Temperature
- Light/Grazing

B) Small Phytoplankton Growth Limitation

Nitrogen 49.75%, Iron 39.08%, Phosphorus 1.944%
Replete 9.213%

C) Diazotroph Growth Limitation

Nitrogen 0.000%, Iron 36.31%, Phosphorus 26.74%
Replete 6.099%, Temperature 30.84%
A) Sinking POC Flux = 7.95 GtC at 100mdev.20th.001

B) Sinking bSi Flux = 0.96 * 10^14 molSi

C) Sinking CaCO3 Flux = 0.74 GtC
Conclusions

1) The CESM BEC captures observed nutrient and carbon distributions to first order, suitable for climate studies.

2) There is a positive bias in low latitude surface nutrients and phytoplankton biomass.

3) High latitude surface nutrients are often too low.

4) Oxygen minimum zones are much larger than observed.

5) OMZ expansion leads to excessive water column denitrification and imbalances in the N cycle.

6) We are actively working to address these biases.