Influence of Initial Plankton Conditions and Mixed Layer Depth on the Outcome of Iron-fertilization Experiments

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1. Introduction
2. Model experimental design
3. Sensitivity to mixed layer depth
4. Sensitivity to initial plankton biomass
Introduction

Iron-fertilization induced maximum chlorophyll and maximum TCO$_2$ removal

(De Baar et al., 2005)
Motivation

Mixed layer depth plays a great role in iron-induced biological responses.

How about other factors?
- initial abundance of diatoms and its grazers (mesozooplankton)

Compare biological responses to different mixed layer depth and initial plankton abundance by an ecosystem model
15-compartment ecosystem model
(Fujii et al., 2002; Yamanaka et al., 2004)

- Diatoms
- Mesozooplankton
- Nutrients
Model Experimental Design

The model is applied to SEEDS I (48.5°N, 165°E).

Increase of three photosynthetic parameters of diatoms (max. growth rate, P-I curve and Chl:C ratio)

(Chai et al., 2002; Fujii et al., 2005, 2006; Yoshie et al., 2005)
**Model Sensitivity Study**

<table>
<thead>
<tr>
<th>Mixed layer depth change (1st set of experiments)</th>
<th>Initial diatom biomass (2nd set of experiments)</th>
<th>Initial mesozoo. biomass (3rd set of experiments)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5m, 9.3°C</td>
<td>0.001</td>
<td>0.01</td>
</tr>
<tr>
<td>12.5m, 8.6°C (standard)</td>
<td>0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>17.5m, 7.8°C</td>
<td>0.1</td>
<td>1 (standard)</td>
</tr>
<tr>
<td>22.5m, 7.2°C</td>
<td>1 (standard)</td>
<td>5</td>
</tr>
<tr>
<td>27.5m, 6.8°C</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>42.5m, 5.5°C</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>72.5m, 4.3°C</td>
<td>1000</td>
<td>30</td>
</tr>
</tbody>
</table>
Exp.1: Mixed layer depth change

- **Surface chl.**
  - SEEDS I data
  - MLD=12.5m
  - MLD=27.5m
  - MLD=72.5m

- **Surface Si(OH)₄**
- **Primary production**
- **pCO₂sea**

Day of experiment vs. concentration ([mg m⁻³], [mmol m⁻³], [mgC m⁻² day⁻¹], [µatm])
Exp. 1: Mixed layer depth change

- **Maximum surface chl.**
  - [mg m\(^{-3}\)]
  - Model
  - de Baar et al. (2005)

- **Maximum TCO\(_2\) drawdown**
  - [mmol m\(^{-3}\)]

- **Maximum primary production**
  - [mgC m\(^{-2}\) day\(^{-1}\)]

- **Maximum export production**
  - [mgC m\(^{-2}\) day\(^{-1}\)]

Due to higher temp.
Diatom growth

\[ V_{\text{max}} L \times \exp( k_L \times \text{Temp} ) \]

Temperature dependence (Q_{10} effect)

\[ \times \min \left\{ \frac{[\text{NO}_3^-]}{[\text{NO}_3^-]+K_{\text{NO}_3}}, \frac{[\text{NH}_4^+]}{[\text{NH}_4^+] + K_{\text{NH}_4}}, \frac{[\text{Si(OH)_4}]}{[\text{Si(OH)_4}]+K_{\text{Si(OH)_4}}} \right\} \]

Nutrient regulation

\[ \times \left\{ 1 - \exp\left( -\frac{\alpha \times \text{Light}}{V_{\text{max}} L} \right) \right\} \times \text{Diatom biomass} \]

Light limitation
Diatom growth: $12.3$

Temperature dependence: $1.2$

Nutrient regulation: $1.1$

Light limitation: $1.1$

Diatom biomass: $7.1$
Exp. 2: Initial diatom biomass change

- **Surface chl.**
- **Surface Si(OH)_4**
- **Primary production**
- **pCO_{2sea}**
Exp. 2: Initial diatom biomass change
Exp.3: Initial Mesozoo. biomass change

- **Surface chl.**
  - O SEEDS I data
  - Red: ZLx0.01
  - Black: ZLx1
  - Blue: ZLx30

- **Surface Si(OH)₄**

- **Primary production**

- **pCO₂sea**
Exp. 3: Initial Mesozoo. biomass change

(a) Diatom specific growth rate [day\(^{-1}\)]
(b) Specific grazing rate by mesozooplankton [day\(^{-1}\)]

(c) Diatom biomass [mmol m\(^{-3}\)]
(d) Mesozooplankton biomass [mmol m\(^{-3}\)]

(e) Diatom total growth rate [mmol m\(^{-3}\) day\(^{-1}\)]
(f) Total grazing rate by mesozooplankton [mmol m\(^{-3}\) day\(^{-1}\)]
Mixed layer depth change

Max. surface chl.

Max. surface chl.

Max. export prod.

Max. export prod.

Initial plankton change

Initial PL or ZL biomass

Mixed layer depth [m]

Mixed layer depth [m]

Initial PL or ZL biomass

Initial PL or ZL biomass

Diatoms

Mesozoo.

Ģ = 20

Ģ = 1651

Ģ = 1951

Ģ = 1438

Ģ = 15

Ģ = 14
Summary

• Observed inverse relationship between mixed layer depth and iron-induced biological responses is well reproduced in the model at SEEDS I.

• With deeper mixed layer depth, the diatom production is much lower due to the dilution effect, rather than temperature, nutrient and light regulation.

• Initial plankton abundance also plays an important role in determining the outcome of iron enrichments, especially for carbon fluxes.