Modeling Low-Oxygen Regions

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1. How well can global models simulate low-oxygen regions?
2. Long-term projections
3. Variability
4. Coastal ocean oxygen modeling
5. Paleo perspective

Ocean Carbon and Biogeochemistry (OCB) summer workshop 2010
Scripps Institution of Oceanography
1. How well can global models simulate low-oxygen regions?

UVic Model
(Weaver et al. 2001)

- 2D Energy-Moisture Balance Atmosphere (fixed winds)
- Dyn. Thermod. Sea Ice
- 3D Ocean (1.8x3.6 deg, 19 levels)
- 2N2PZD Ocean Ecosystem / Biogeochemistry Model (Schmittner et al. 2008 GBC)

\[
d\text{N}_2\text{O} / -d\text{O}_2 = R_{\text{N}_2\text{O}_2}(a_1/\text{O}_2 + a_2) \exp(-Z/Z_{\text{scale}})
\]

\[
\text{O}_2 > \text{O}_2,\text{crit}; \ Z > \text{Z}_{\text{euph}},
\]

\[O_2,\text{crit}=4\pm3\mu\text{M}\]
1. How well can global models simulate low-oxygen regions?

Schmittner et al. (2007) Paleoceanography
1. How well can global models simulate low-oxygen regions?
How well can global models simulate low-oxygen regions?

• Large scale oxygen distribution can be modeled well

• Low-oxygen regions not so well. Typically suboxic volume overestimated. Issues: physics (resolution, mixing parameterizations), biology (zooplankton vertical migration, ...)

2. Long-Term Projections

Global Warming until year 4000

- Business-as-usual based on burning of all readily available fossil fuel reserves (SRES A2, linear decrease from 2100-2300)

Schmittner et al. (2008)

Sea Ice Disappears

Sea Level Rises
(only thermal expansion)
Impacts on Ocean Circulation and Productivity

Schmittner et al. (2008)
GBC

2. Long-term projections

NPP doubles
New Production
Export Production

Schmittner et al. (2008)
GBC
2. Long-term projections

- Oxygen decreases
- Suboxic water volume increases
- Denitrification increases by 350%
- Nitrogen fixation increases
- Decrease in NO$_3$ inventory small
- N$_2$O production increases by 64% (estimated from empirical relation by Nevison et al., 2003)

- => atmospheric N$_2$O increases by 60 ppb (21%)
- => additional warming by 0.2ºC

Schmittner et al. (2008)
GBC
Dissolved Oxygen Change (%)

Time (years)
2. Long-term projections

Year 4000

300 m depth

Oxygen Change (percent)
Oxygen on $\sigma_\Theta = 27.0$ kg/m$^3$ year 2100

2. Long-term projections

Effects of C:N changes

“Gnanadesikan et al. (2007) Ocean Sci. effect” reduced upwelling

Oschlies et al. (2008) GBC
Acidification effects (decreased ballasting)

Hofmann & Schellnhuber 2009 PNAS
Table 2  Model predictions of average ocean O$_2$ decrease by year 2100

<table>
<thead>
<tr>
<th>Study</th>
<th>Model</th>
<th>Forcing</th>
<th>O$_2$ decrease (µmol kg$^{-1}$)$^a$</th>
<th>Solubility contribution (%)</th>
<th>O$_2$/Heat ratio nmol J$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarmiento et al. (1998)</td>
<td>GFDL</td>
<td></td>
<td>7$^b$</td>
<td></td>
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<tr>
<td>Matear et al. (2000)</td>
<td>CSIRO</td>
<td>IS92A</td>
<td>7</td>
<td>18</td>
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<td>Plattner et al. (2001, 2002)</td>
<td>Bern 2D</td>
<td>SRES A1</td>
<td>12</td>
<td>35</td>
<td>5.9$^c$</td>
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<tr>
<td>Bopp et al. (2002)</td>
<td>OPAICE-LMD5</td>
<td>SRES A2 CO$_2$ only</td>
<td>4</td>
<td>25</td>
<td>6.1</td>
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<td>HAMOCC-3</td>
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<td>Matear &amp; Hirst (2003)</td>
<td>CSIRO</td>
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<td>9</td>
<td>26</td>
<td>6.6</td>
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<td>UVic-variable C/N</td>
<td>SRES A2</td>
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<td>Frölicher et al. (2009)</td>
<td>NCAR CSM1.4-CCCM</td>
<td>SRES A2</td>
<td>4</td>
<td>50</td>
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<tr>
<td></td>
<td>SRES B1</td>
<td></td>
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</tbody>
</table>
3. Long-Term Projections

Dissolved Oxygen is projected to decrease world-wide due to

- decreased solubility
- increased stratification / slower circulation

Low-oxygen regions will expand, perhaps dramatically

- increased denitrification
- increased N\textsubscript{2}O production (very small positive climate feedback)

Biological effects of acidification may
Variability: Atlantic

Fröhlicher et al., 2009, GBC
Variability: Pacific

Fröhlicher et al., 2009, GBC
Variability: Pacific

Deutsch et al. (2006) GBC
Variability

• Much of the observed changes due to internal variability
• Models capture variability in North Atlantic
• Models underestimate variability in North Pacific
4. Coastal Models

**Biological-physical model configuration**

**ROMS:**
3 km horizontal & 40 s-layers vertical resolution

**Model runs:**

**Atmospheric forcing:**
2002: COAMPS winds & NCEP heat flux
2006, 2008: NAM winds & heat flux

**Oceanic forcing:**
NCOM-CCS (I. Shulman, S. DeRada)

**Biological forcing:**
NCOM-CCS 2006, 2008

**Oxygen OBC & IC:** empirical
NO$_3$:O$_2$ ratio derived from GLOBEC-LTOP observations in the Oregon CTZ

Spitz, Batchelder, Koch CLOSS Project
4. Coastal Models

2002 GLOBEC - LTOP data

Climatology

Spitz, Batchelder, Koch CIOSS Project
Coastal Models

• Important to predict local occurrence of hypoxia
• Boundary conditions crucial
De Pol-Holz et al. (2006)

Emmer and Thrunell (2000)

Altabet et al. (2002)

Ren et al. (2009)
LGM preliminary model results

<table>
<thead>
<tr>
<th></th>
<th>Solid Lines</th>
<th>Dashed Lines</th>
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<tbody>
<tr>
<td>Fe Limitation</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Sedim. Denitrification</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>AMOC</td>
<td>collapsed</td>
<td>not collapsed</td>
</tr>
</tbody>
</table>
δ15N of Sinking Organic Matter (200 m)

LGM

Funded by NSF MG&G

Difference

LGM - Present

Chris Somes
Paleo Perspective

- Provides information on past episodes of ocean deoxygenation and effects on biogeochemical cycles (e.g. N-cycle)
- Models including N-isotopes are now available and can provide quantitative constraints in combination with observations
Thanks
Paleo:
Effects of Ocean Circulation Changes
Shutdown of Atlantic Meridional Overturning Circulation

Schmittner et al. (2007) Paleoceanography
Comparison with Ice Core Record

- Model reproduces $\text{N}_2\text{O}$ amplitude and timescale

![Graph showing comparison between model and ice core record](image)

- Time [Graph showing time scale]
Productivity Decreases

Schmittner 2005 Nature
UVic Model
(Weaver et al. 2001)

2D Energy-Moisture Balance
Atmosphere
(fixed winds)

Dyn. Thermod. Sea Ice

3D Ocean Circulation
(MOM)
(1-1.8)x3.6, 19 levels

2N2PZD Ocean
Ecosystem /
Biogeochemistry
Model
(Schmittner et al. 2008 GBC)

Assumptions:
• Constant Elemental Ratios
• No DOM
• No N-Deposition
• No River Input of N

$\delta^{15}$N Model
Somes et al., 2010 GBC subm.

$\delta^{15}$N=0‰

Assumptions:
• Constant Elemental Ratios
• No DOM
• No N-Deposition
• No River Input of N

$\epsilon_{\text{DENI}}=25\%$
$\epsilon_{\text{ASSIM}}=5\%$
$\epsilon_{\text{NFIx}}=1.5\%$
$\epsilon_{\text{EXCR}}=6\%$

$tuned to reproduce global mean $^{15}$N

Middleburg et al. [1996]
Model/data comparisons: cross-sections of Chl-a, O$_2$

at 44.65N on 10 July 2002

model – color
data – contours