Possible Long-Term Impacts of Anthropogenic Carbon Emissions

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Climate Impacts Group, Seattle, Sept. 30th, 2008
• Motivation
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• A Business-as-Usual Scenario
• Simulated Impacts on Climate, Ocean Circulation, Ecosystems and Biogeochemical Cycles
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Emission Estimates from the 1990's

Motivation

2007 8.5 GtC
Global Carbon Project (2008)

Bern model (Joos & Siegenthaler)
Enting et al., (1994)
Model Description

The UVic ESCM *(Weaver et al., 2001)*
(University of Victoria Earth System Climate Model)

- 3D ocean primitive equations model (MOM2) 3.6x1.8 deg., 19 levels, *Gent & McWilliams (1990)*, tidal mixing scheme *(Simmons et al. 2004)* with low $K_v=0.2\text{cm}^2/\text{s}$ in pelagic pycnocline

- one layer 2D energy-moisture balance atmosphere model (fixed winds)

- Dynamic-thermodynamic sea ice model *(Bitz et al., 2001)*

- Dynamic terrestrial vegetation and carbon cycle *(Meissner et al. 2003)*

- Dynamic ocean ecosystem and carbon cycle
The Ecosystem Model (Schmittner et al., 2005 GBC; Schmittner et al., 2007 GBC) with help from Andreas Oschlies and Eric Galbraith

- CaCO$_3$ production rate ~ POC production:
  \[ S(\text{CaCO}_3) = R_{\text{PIC/POC}} S(D) \]

- Instantaneous sinking of calcite and dissolution according to prescribed exponential depth profile with e-folding depth of 3500 m

- Acidification effects on calcite production not considered!

- Constant elemental ratios C:P:N:O = 112:1:16:208
The Eppley (1972) Curve

Fig. 1. Variation in the specific growth rate ($\mu$) of photosynthetic unicellular algae with temperature. Data are all for laboratory cultures. Growth rate is expressed in doublings per day (from Eppley 1972).
The Rain Ratio (at 120 m)

Square Symbols: Sarmiento et al., 2002
Triangles: Jin et al., 2006

Red: Atlantic
Green: Pacific
Blue: Indian Ocean
Black: Global
Model Evaluation

Forced with historical C emissions, solar, volcanic, aerosol and land use changes

Surface Air Temperature

Red: Model
Black: Observations (Jones et al. 2001)
Summary of Detailed Evaluation

(Schmittner et al., 2008, GBC)

- Model results of a large number of physical and biogeochemical tracers (T, S, Δ^{14}C, CFC, PO_{4}, NO_{3}, O_{2} (AOU), DIC, ALK) are broadly consistent with observations

- All metrics of Matsumoto et al. (2004) are met

- Anthropogenic carbon uptake consistent with observational estimates (e.g. Sabine et al., 2004)
Future Scenario

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

Delay of ~200 years between start of emissions reductions and peak in atmospheric CO₂

At time of emissions peak atmospheric CO₂ < 1000 ppmv
A business-as-usual scenario

Three model versions run until year 4000 AD

1. Full model
2. Constant climate run (no effect of CO$_2$ changes on radiative balance): isolates climate-carbon cycle feedback
3. No ocean biology (inorganic ocean carbon cycle only): isolates solubility effects
Impacts on Carbon Cycle

Climate-Carbon Cycle Feedback (=42% at year 4000)

Ocean Biology Effect
Impacts on Carbon Cycle

Atmosphere

Ocean

Land

Cumulative Emissions (GtC)

Inventories (percent)

Climate-Carbon Cycle Feedback (percent)

Time (years AD)
Impacts on Climate

- 9°C Warming
- Sea Ice Disappears
- Sea Level Rises (only thermal expansion)
Impacts on Climate

Ocean Temperatures

Temperature Change (°C)
Impacts on Climate

Impacts on Ocean Circulation
Impacts on Climate
Impacts on Ocean Ecosystem

NPP doubles

New Production

and

Export Production decline temporarily
Impacts on Ocean Ecosystem

Biomass

Initially no change in global phytoplankton biomass due to competing effects of temperature (higher growth rates) and stratification (decreased nutrient input). In the long term temperature effect dominates as circulation recovers.

Nitrogen fixers increase earlier due to more denitrification. This increases their ecological niche (low nitrate, high phosphate surface waters).

Zooplankton biomass follows global food supply (total phytoplankton biomass).
Impact on Biogeochemical Cycles

• Oxygen decreases
• Suboxic water volume increases
• Denitrification increases
• Nitrogen fixation increases
• N₂O production increases by 64%
  (estimated from empirical relation by Nevison et al., 2003)
  • => atmospheric N₂O increases by 60 ppb (21%)
  • => additional warming by 0.2°C
Impacts on Biogeochemical Cycles

year 4000

Oxygen Change (percent)
Effects of pCO$_2$ induced C:N increase on future oxygen concentrations

Oschlies, Schulz, Riebesell and Schmittner, GBC (in press)

- Based on experimental finding of Riebesell et al., 2007 Nature
Oxygen on $\sigma_\Theta=27.0$ kg/m$^3$

year 2100

Obs

Model

C:N fixed

$\Delta O_2$

$C:N (pCO_2)$
Conclusions

• anthropogenic CO\textsubscript{2} will stay in the ocean-atmosphere-biosphere system for thousands of years

• lag (~200 years) between start of emission reductions and peak atmospheric CO\textsubscript{2}

• large climate changes likely in business-as-usual scenario
Conclusions

• climate-carbon cycle feedback might be influenced by changes in ocean ecosystem

• response of ocean biology remains highly uncertain

• improved ocean ecosystem models needed
Thank You