Trends in the North Atlantic Carbon Sink

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Effects of Climate Change on the World’s Oceans
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Overview

• N. Atlantic carbon cycle variability, data
• N. Atlantic regional model
• Basin-scale flux trend, 1992-2006
• Mechanisms driving flux change
Temperature, DIC, pCO$_2$
1983-2005, merged Hydrostation S and BATS

Bates, 2007
Understanding observed trends in $\Delta p\text{CO}_2$

50% sink reduction 94-95 to 02-04

Schuster and Watson, 2007
Summary for mid-1990’s to early 2000’s (Schuster and Watson, 2007)

- Regions 1-4 are declining in CO$_2$ uptake
- Region 5, 6 are neutral or increasing CO$_2$ flux
Modeling the North Atlantic carbon cycle
A North Atlantic regional model...

- MITgcm, 20S-80N
- 0.5 x 0.5 horizontal, 23 vertical
- Parameterizations
  - GM-Redi (isopycnal mixing)
  - KPP (mixed layer)
- Forcing:
  - daily NCEP
  - SST restored to Reynolds et al 2002
- 90 year physical spinup
- 10 year biogeochemical spinup
- 15 year (1992-2006) run

Sea Surface Temperature
Mixed layer depth at Bermuda

Model (red) captures mixing reasonably well
Ecosystem and carbon cycle

- Dutkiewicz et al. (2005) ecosystem
- 2 phytoplankton, 1 zooplankton class, dissolved and particulate detritus
- Explicit silica and iron
- Coupled carbon and oxygen cycles
pCO₂ seasonal cycle at Bermuda, Data and model
\[ pCO_2 - T = pCO_2 \cdot \exp[0.0423(T - \bar{T})] \]
\[ pCO_2 - nonT = pCO_2 \cdot \exp[0.0423(\bar{T} - T)] \]

Takahashi et al, 2002
Low frequency (>1 year) pCO$_2$ variability at Bermuda

Model-data correlation, $r = 0.49$
Low frequency (>1 year) pCO$_2$ variability at Bermuda

pCO$_2$-nonT ($r = 0.65$)
pCO$_2$-T ($r = 0.47$)
Variability and trends across the North Atlantic

1992-2006
Basin-scale CO$_2$ flux variability compared to Takahashi et al. 2002 in 1995.
EOF1

$pCO_2$ and CO$_2$ flux

PC1 of $pCO_2$ (blue) and flux (red) $r = 0.87$
What drives the modeled trend?

Consider difference of 4yr means
Flux trend vs. Observations

- Consistent with available data in West, East, South
- Not consistent in North
Ocean pCO$_2$ trend
pCO$_2$ and component trends
Summary: pCO$_2$ Trends

- Model illustrates Northwest/Southeast asymmetry in flux trend
  - In West, East & South: consistent with data
- Due to combined effect of SST, DIC and ALK on ocean pCO$_2$
  - SST change consistent with data, including intensification in Northwest (ICES, 2006)
  - What drives DIC change?
DIC change

-200 uatm

-20 mmol/m³/yr

20 mmol/m³/yr

HORIZONTAL CIRCULATION

VERTICAL CIRCULATION

BIOLOGY

FRESHWATER

HORIZONTAL CIRCULATION
Conclusions

Surface ocean carbon cycle trends, North Atlantic, 1992-2006

- Model captures pCO$_2$ trend, mechanisms at BATS
- pCO$_2$ increase spatially variable, max 30 $\mu$atm
  - pCO$_2$-SST, pCO$_2$-ALK, pCO$_2$-DIC trend $\pm$200 $\mu$atm, but largely counteract each other
  - Vertical mixing, biology, freshwater and horizontal transport all contribute to pCO$_2$-DIC trend
    - Vertical, biology, freshwater changes consistent with data
- Observed $\Delta$pCO$_2$ trends can be partially explained while the basin-wide sink increases
Observed Temperature Trend

ICES, 2006
Observed Salinity Trend
ICES, 2006
\( \Delta p\text{CO}_2 \) trend

June chlorophyll, STD 98-05
log10(mg Chl/m³)