Ocean physics and biogeochemistry

Matthew Long

Climate and Global Dynamics Division
National Center for Atmospheric Research

G. Danabasoglu, S. Doney, P. Gent, M. Jochum, K. Lindsay,
N. Lovenduski, J. K. Moore, S. Peacock

Ocean Model Working Group Meeting
Breckenridge, CO
19 June 2012
RCP8.5 21st century

Surface CO₂ fluxes

Ocean CO₂ uptake

:: Introduction ::
Ocean uptake: circulation is rate limiting

Anthropogenic $p\text{CO}_2^{\text{atm}}$ perturbation

\[ \tau \approx 50 \text{ yr} \]

![Graph showing $p\text{CO}_2^{\text{atm}}$ vs. Year]

Gas exchange timescale ($\tau = \frac{h}{k}$)

\[ \tau \approx 6 \text{ mon} \]

![Graph showing gas exchange timescale vs. Wind speed]

Ventilation age

\[ \tau \approx \mathcal{O}(10^0 - 10^1) \text{ yr} \]

![Graph showing ventilation age vs. Age [yr]]
Biological pump

AIR-SEA FLUX

LIGHT

0 m

Dissolved CO₂ & Nutrients

Phytoplankton

Organic Matter & Oxygen

~100 m

Transport

Dissolved CO₂ & Nutrients

Bacteria + Zooplankton

Organic Matter & Oxygen

Surface Ocean

Thermocline and Deep Ocean

Sarmiento & Gruber 2006
Nonlinear carbon chemistry

Carbon in seawater

\[ \text{CO}_2,\text{gas} + \text{H}_2\text{O} + \text{CO}_3^{2-} \rightleftharpoons 2\text{HCO}_3^- \]

\[ \text{DIC} = \text{Dissolved inorganic carbon} = [\text{CO}_2] + [\text{HCO}_3^-] + [\text{CO}_3^{2-}] \]

Sarmiento & Gruber 2006
21st century ocean sink

Time-integrated flux anomaly

- Intense uptake in North Atlantic and Southern Ocean;
- Reduced outgassing in Equatorial Pacific.
Climate response in 21st century ocean sink
RCP8.5 sea-air CO$_2$ flux

Climate-induced DIC anomaly

North Atlantic

Southern Ocean

Year

2020 2040 2060 2080 2100

PG yr$^{-1}$

Full system

No climate change

ΔCarbon Storage [mol m$^{-2}$]

-90 -60 -30 0 30 60 90

:: 21st century results ::
Ventilation rates

Meridional overturning circulation

- Poleward shift and slight intensification of Deacon Cell;
- Shoaling and reduction in North Atlantic overturning;
- AABW production reduced.
Mechanisms forcing climate response

Climate impact (full system minus constant climate integration)

- **ΔSea-air CO₂ flux [mol m⁻² yr⁻¹]**
  - 8.5PRES
  - 2.4 -1.8 -1.2 -0.6 0 0.6 1.2 1.8 2.4

- **ΔWinter MLD [%]**
  - 8.5PRES
  - -48 -36 -24 -12 0 12 24 36 48

- **ΔExport flux [mol m⁻² yr⁻¹]**
  - 8.5PRES
  - -1.8 -1.2 -0.6 0 0.6 1.2 1.8

- **ΔSurface CO₃²⁻ [mmol m⁻³]**
  - 8.5PRES
  - -24 -18 -12 -6 0 6 12 18 24
Reductions in surface nutrient

Zonal-mean surface nitrate
21st century ocean sink

Source waters

Sarmiento & Gruber [2006]
Processes controlling ventilation rates are a fundamental constraint on nutrient cycles and transient tracer uptake.

Ocean carbon sink stabilizes in the late 21st century under RCP8.5 due to chemistry feedbacks; climate feedbacks cause further reductions in sink strength.

Differing circulation dynamics and biological response force different carbon cycle responses in the Southern Ocean and North Atlantic during the 21st century.
21st century ocean sink

Mechanisms forcing flux trends

Trend components

- Total
- ΔpCO₂
- SST
- sAlk
- Ice

2005-2050
2080-2100

Flux trend [mol m⁻² yr⁻¹]

Atlant 44°S-18°S 18°S-18°N 18°N-49°N >49°N

:: Summary ::
Trends in coupled model Southern Hemisphere windstress

Maximum zonal-mean zonal wind

11-year running mean

NCEP reanalysis
(+0.1 N m$^{-2}$ offset)

CESM Coupled (CAM4)

Control ± 1σ
(900 years)
Residual mean theory

Marshall and Radko, JPO, 2003
Southern Ocean CO₂ fluxes

Spatially-integrated fluxes (south of 45°S)

- Natural: +0.007 Pg yr⁻²
- Contemporary Anthropogenic:
  - Advection: 0.103 ± 0.024 Pg yr⁻¹ decade⁻¹
  - Lateral mix.: −0.054 ± 0.010 Pg yr⁻¹ decade⁻¹
  - Vertical mix.: 0.062 ± 0.022 Pg yr⁻¹ decade⁻¹
  - NCP: 0.028 ± 0.012 Pg yr⁻¹ decade⁻¹

:: Response to winds ::
Variable eddy-induced advection coefficient

Upper ocean DIC budget \((z > -100 \text{ m})\)

### Southern Oc.

- **158 Pg**
- **+0.40 Pg**

**Fluxes:** [Pg yr\(^{-1}\)]
- **1958-1967**
- **Change (1998-2007)**

![Diagram showing fluxes and balances](image)

- Gas ex.
- Virtual
- Lat. adv.
- Isopyc. mix.
- Diapyc. mix.
- NCP

- 20.57
- 3.19
- 0.38
- 0.18
- 1.80
- 0.23
- 0.10
- -2.03
- -19.32
- -2.85
- -0.14
- -0.02

- :: Response to winds ::
Variable eddy-induced advection coefficient

Trend in $\kappa$

Trend in eddy-induced DIC flux

Lovenduski et al., submitted to GRL

:: Response to winds ::