Southern Ocean carbon: Key open questions

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Part 1: The mean state
Observed Southern Ocean CO$_2$ fluxes

Takahashi et al. (2009)
Integrated (<44°S) sea-air CO$_2$ flux

data from Gruber et al. (2009)
Why the model spread?

Getting the physics “right”

Orr et al. (2002)
Getting the biology “right”

The MAREMIP project: Phase I results

SeaWiFS

CCSM-BEC

NEMURO

PISCES

Green

Surface chlorophyll concentration \([\ln(\text{mg m}^{-3})]\)
Key open questions:

The mean state

1. How large is the Southern Ocean CO$_2$ sink?

2. Can we accurately model CO$_2$ uptake?
   a) Accurately representing physics
   b) Accurately representing ecology
Part 2: Historical variability & trends
Historical evolution of CO$_2$ exchange
Historical evolution of CO\textsubscript{2} exchange
Variability in sea-air CO$_2$ flux

Lovenduski et al. (2008)
SAM drives CO$_2$ flux variability

Lovenduski et al. (2007)
SAM drives CO$_2$ flux trend

natural CO$_2$ flux trend

trend congruent with SAM

Lovenduski et al. (2008)
Mechanism linking SAM to \( \text{CO}_2 \) flux

Lovenduski et al. (2008)

stronger wind stress

increased meridional overturning

zonal-mean dissolved inorganic carbon

Lovenduski et al. (2008)
The great eddy debate

Can coarse-resolution ocean models simulate an appropriate response to increasing Southern Hemisphere winds?

a few references ...

Hallberg and Gnanadesikan (2006)
Boning et al. (2008)
Hogg et al. (2008)
Screen et al. (2009)
Farneti et al. (2010)
Spence et al. (2010)
Farneti and Gent (2011)
Gent and Danabasoglu (in press)
Observed pCO$_2$ trend

Takahashi et al. (2009)
Observed $\Delta^{14}C$ in Drake Passage

Sweeney et al. (in prep.)
Key open questions:

Historical variability & trends

1. How do eddies respond to increasing wind stress?

2. Can we observe variability and trends?
   1. physical circulation
   2. CO$_2$ fluxes, storage
   3. ecology
Part 3: Future changes
Wind-driven circulation

Δ meridional overturning

GHG simulation

Δ meridional overturning

ozone recovery simulation

Sigmond et al. (2011)
Stratification

Southern Ocean integrated sea-air CO$_2$ flux

Lovenduski and Ito (2009)
Acidification

$\Delta \text{CO}_3^{2-}$ in 2100

$\Delta \text{CO}_3^{2-} = [\text{CO}_3^{2-}] - [\text{CO}_3^{2-}]_{\text{sat}}$

Orr et al. (2005)
Key open questions:

Future changes

1. Stratification of the Southern Ocean
   1. How much stratification should we expect?
   2. How will this impact carbon and ecology?

2. Wind-driven circulation changes
   1. Will the wind stress continue to increase?
   2. How will this impact carbon and ecology?

3. How quickly will Southern Ocean acidification proceed?
For more information: