Carbon as Velcro:
Connecting physical climate variability and biogeochemical dynamics in the Southern Ocean

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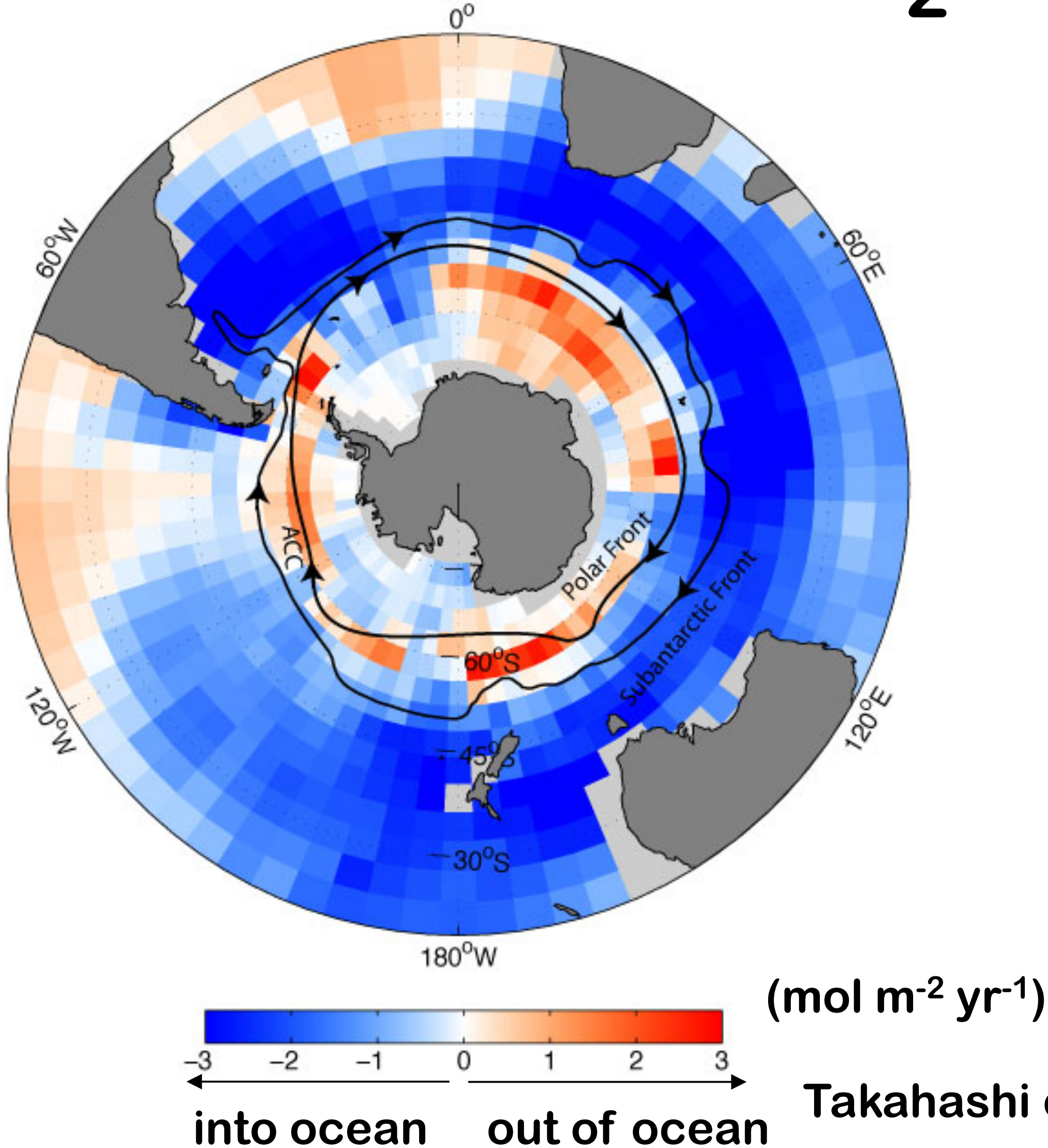
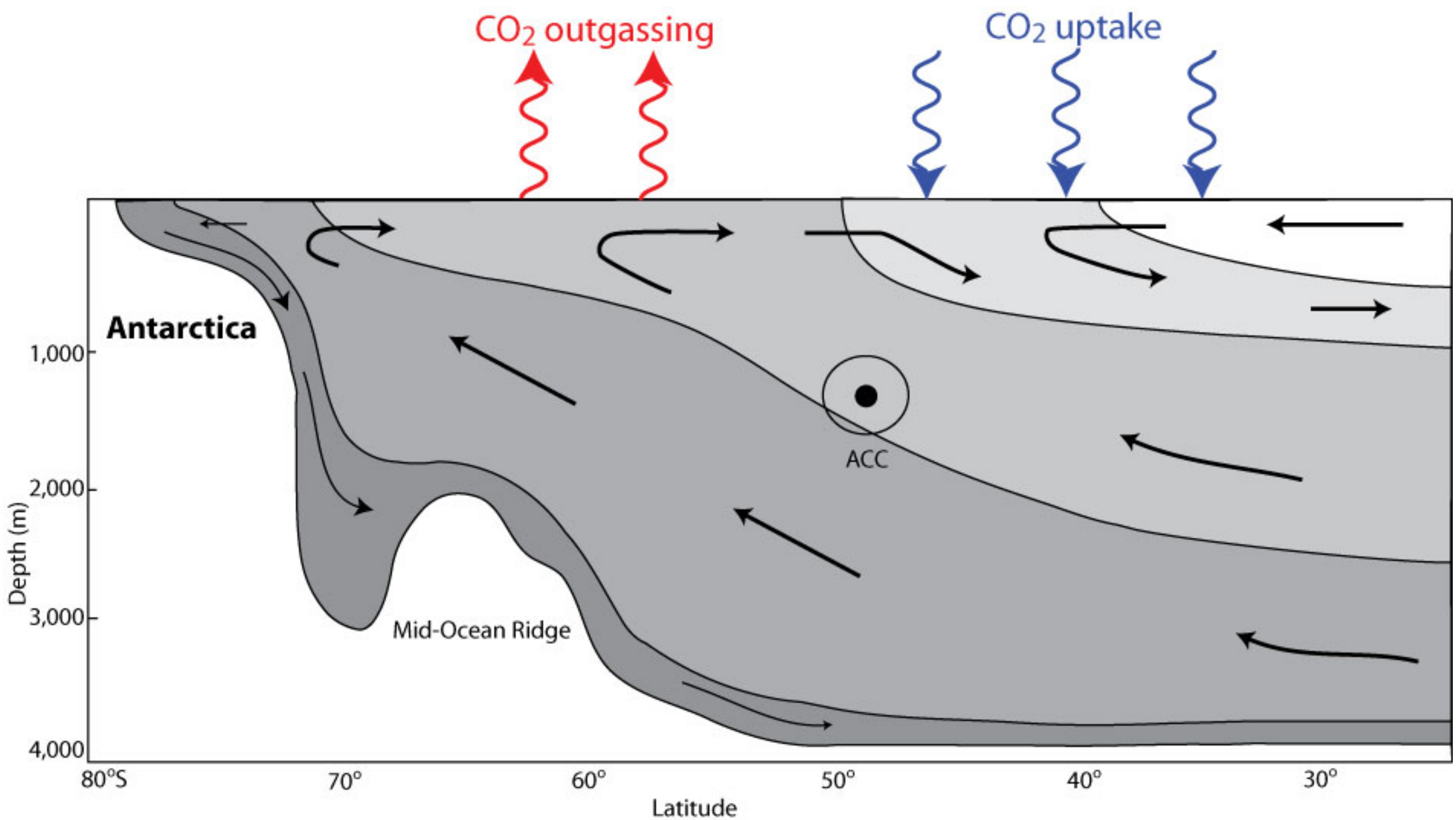
Part 1: The Mean State

Observed sea-air CO_2 flux



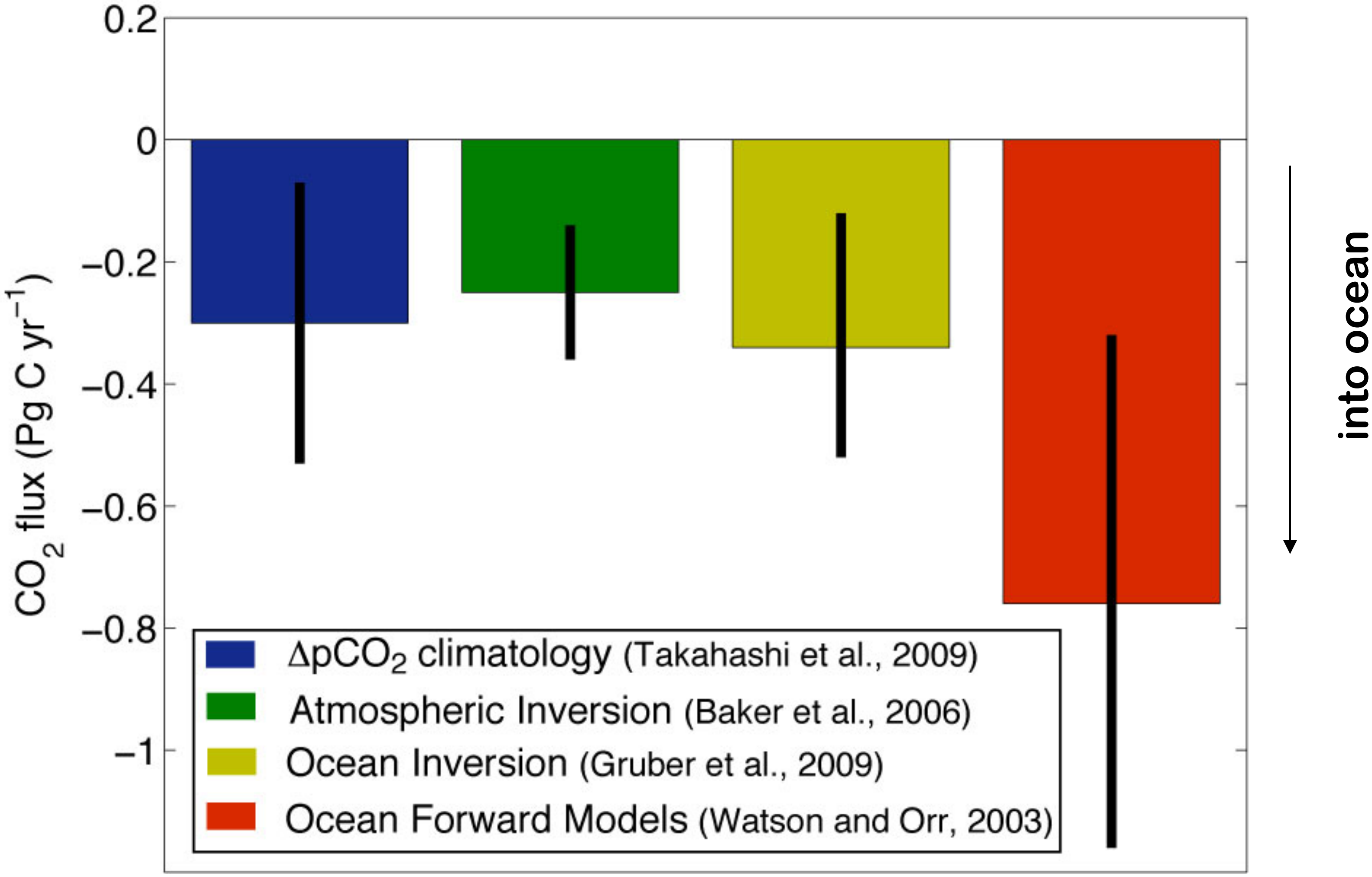
Takahashi et al. (2009)

Ocean circulation and CO_2



Modified from Speer et al. (2000)

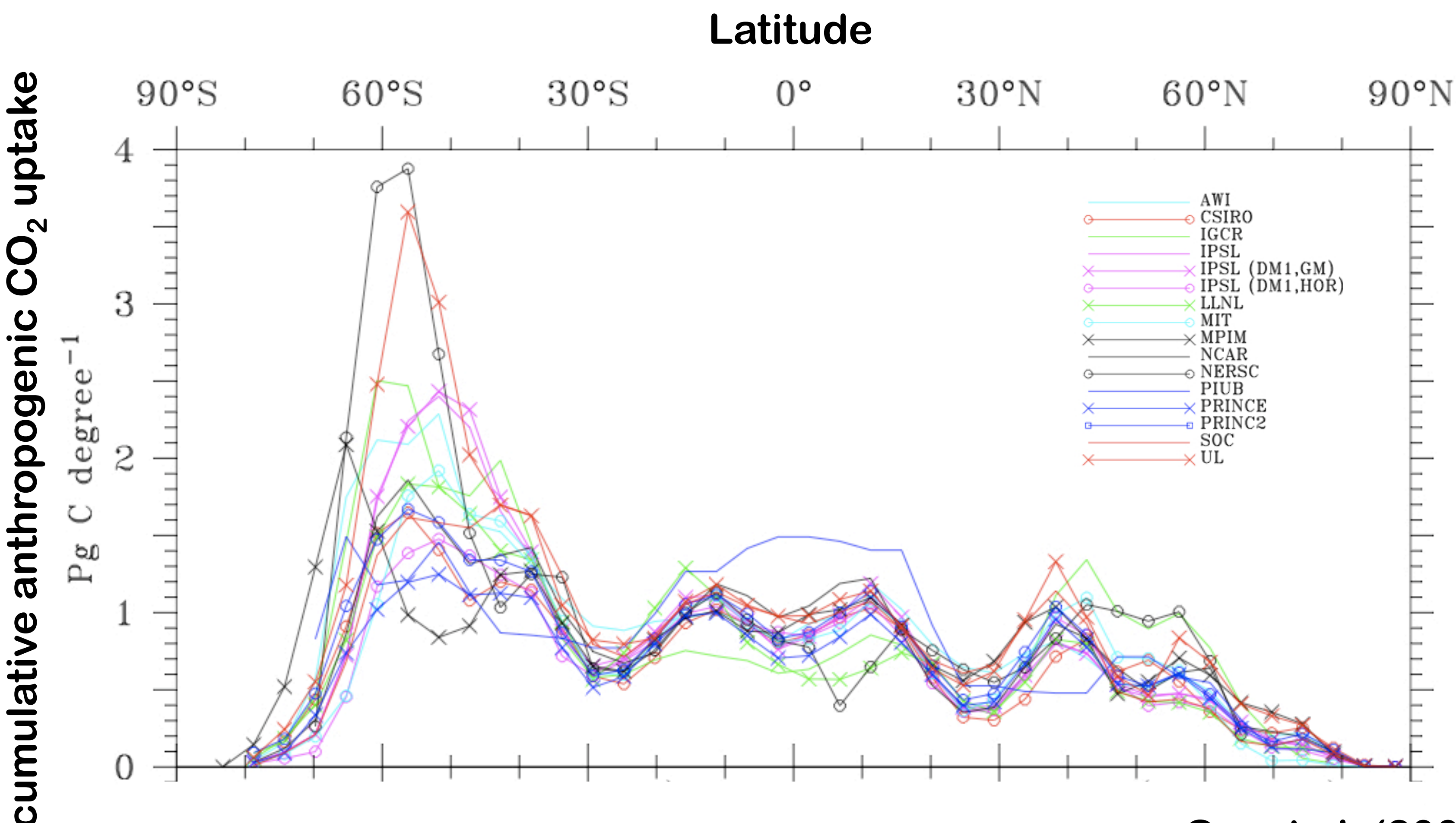
Integrated (<44°S) sea-air CO_2 flux



data from Gruber et al. (2009)

Why the model spread?

Getting the physics “right”

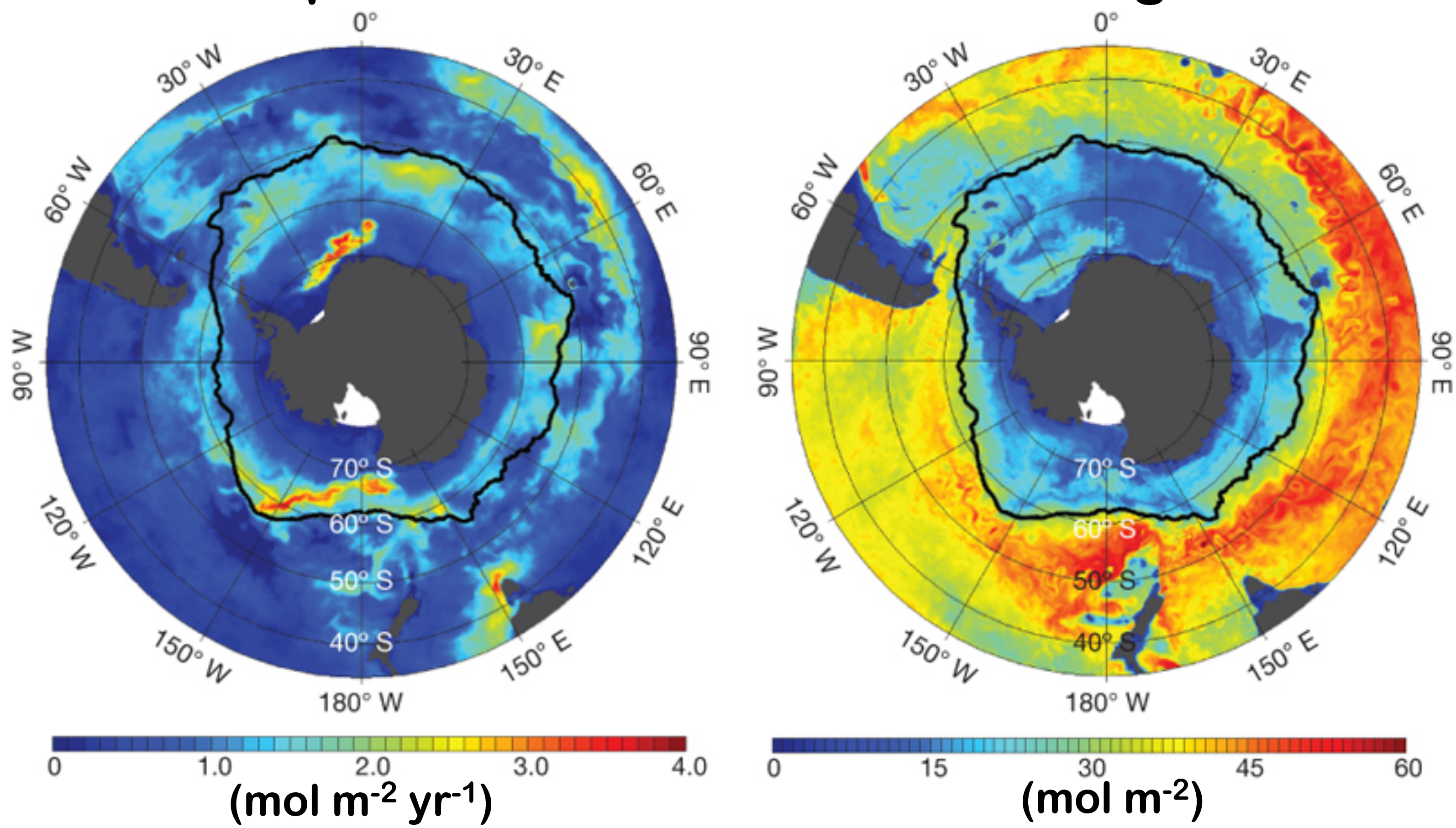


Orr et al. (2002)

Small-scale variability

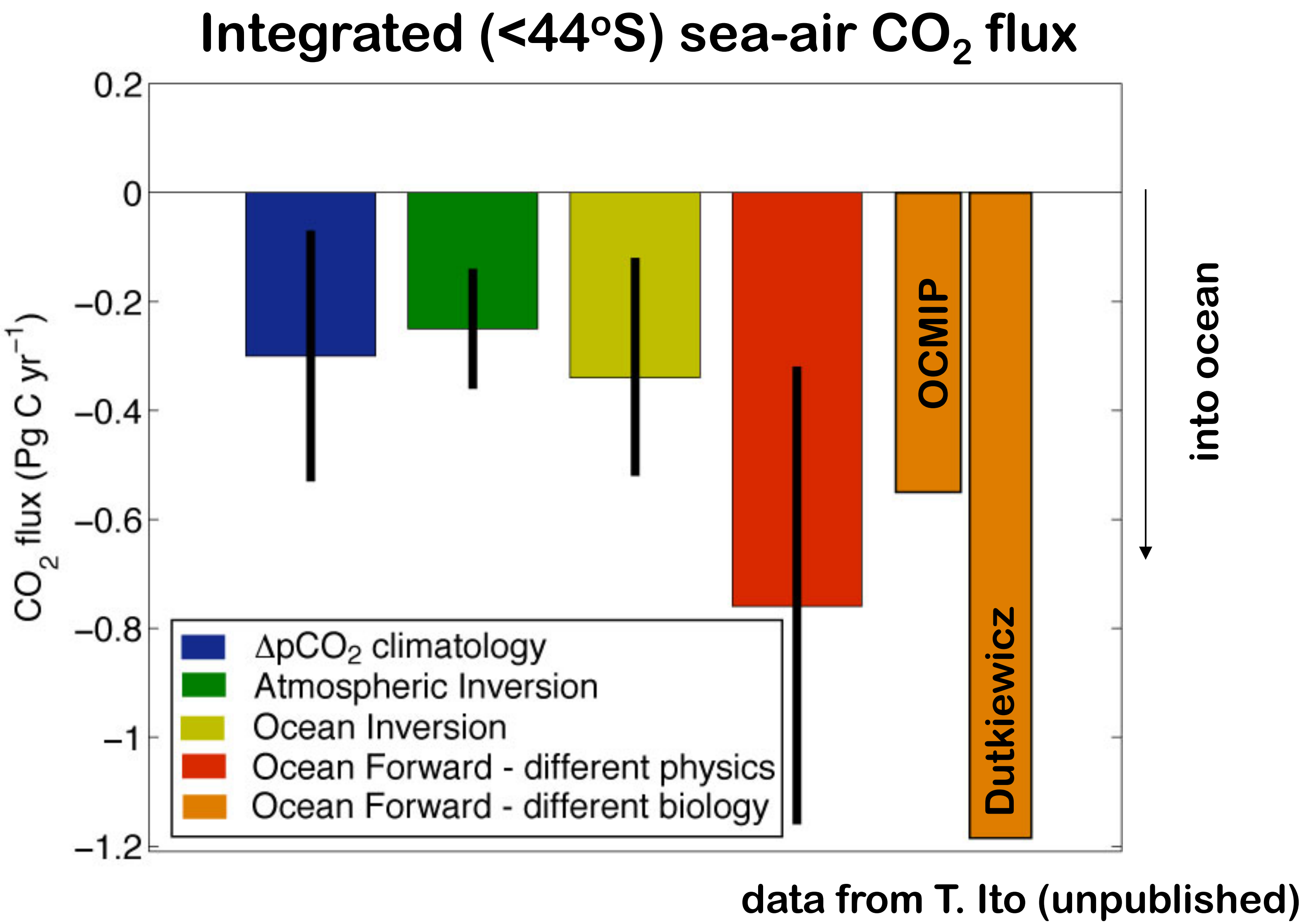
Anthropogenic CO_2

uptake **storage**



Ito et al. (2010)

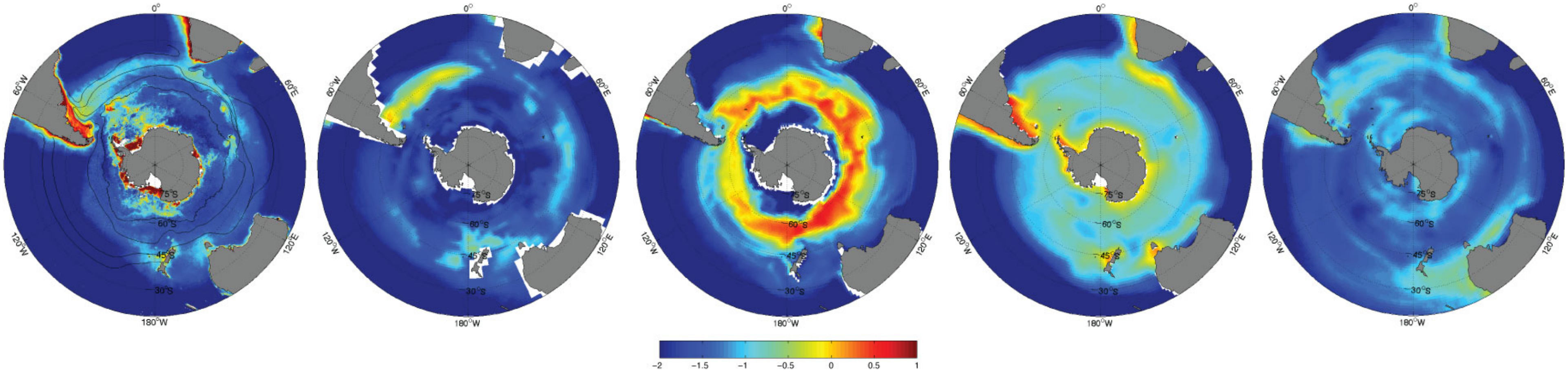
Ecologists aren't off the hook!



Modeling the ecosystem

The MAREMIP project: Phase I results

SeaWiFS CCSM-BEC NEMURO PISCES Green

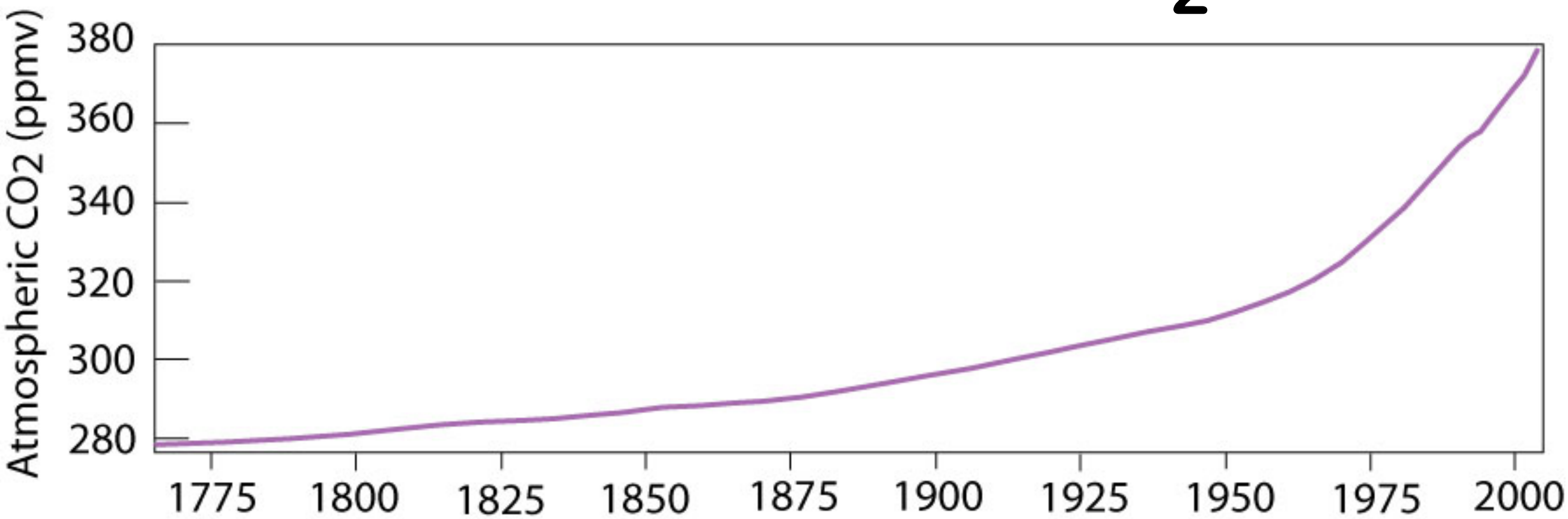


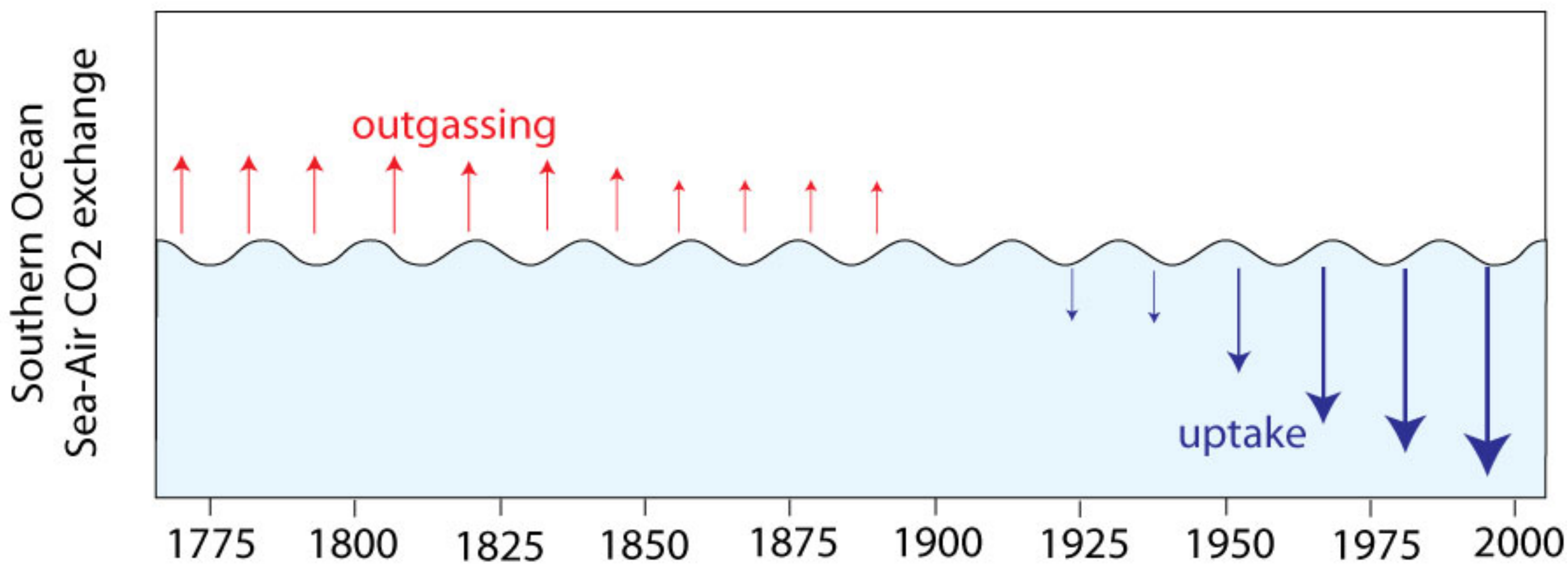
surface chlorophyll concentration [ln(mg m^{-3})]

data provided by M. Vogt

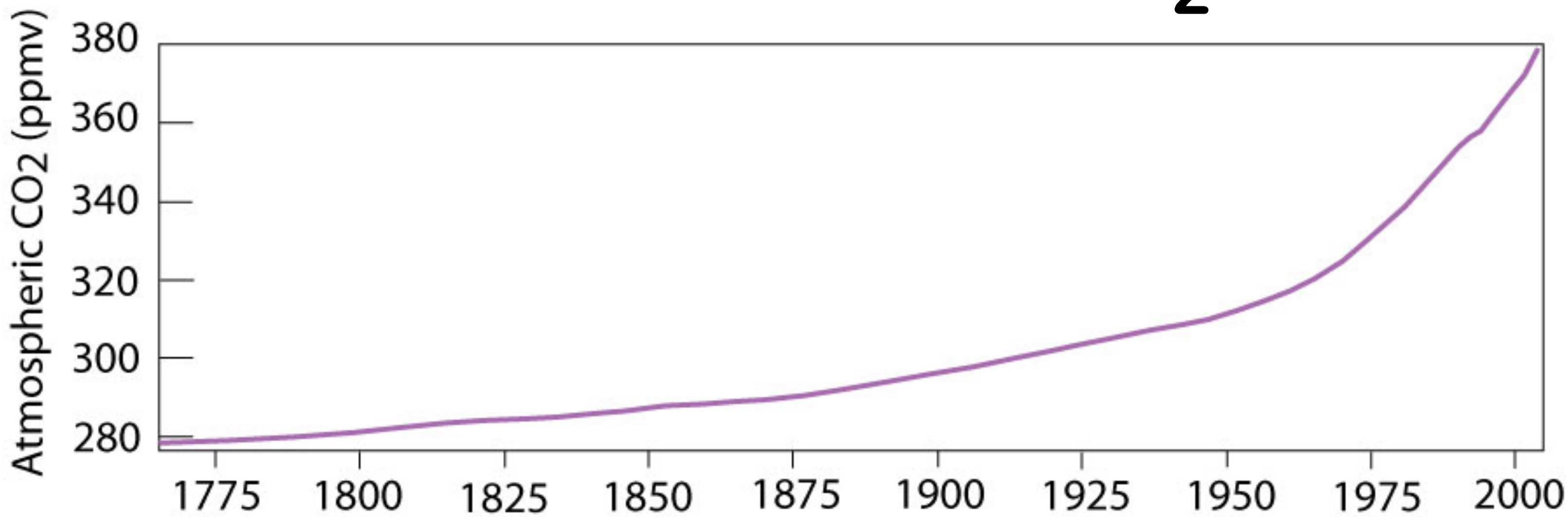
Part 2: Variability

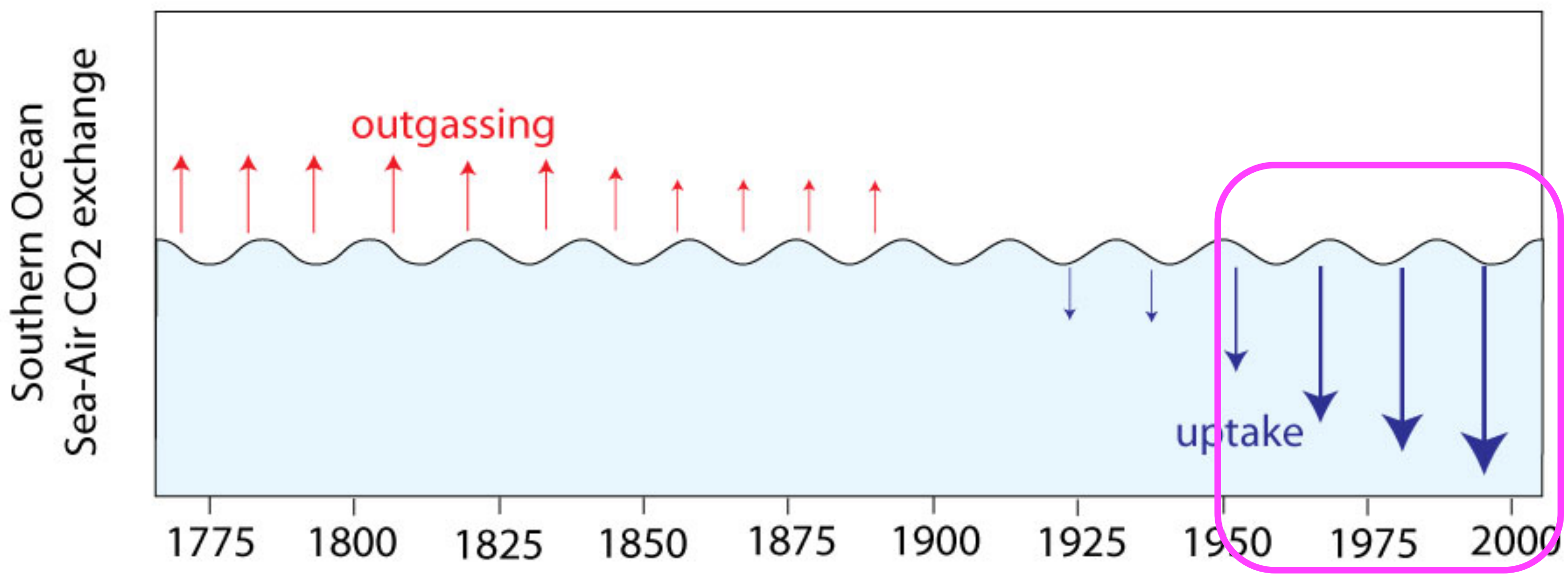
Historical evolution of CO_2 exchange



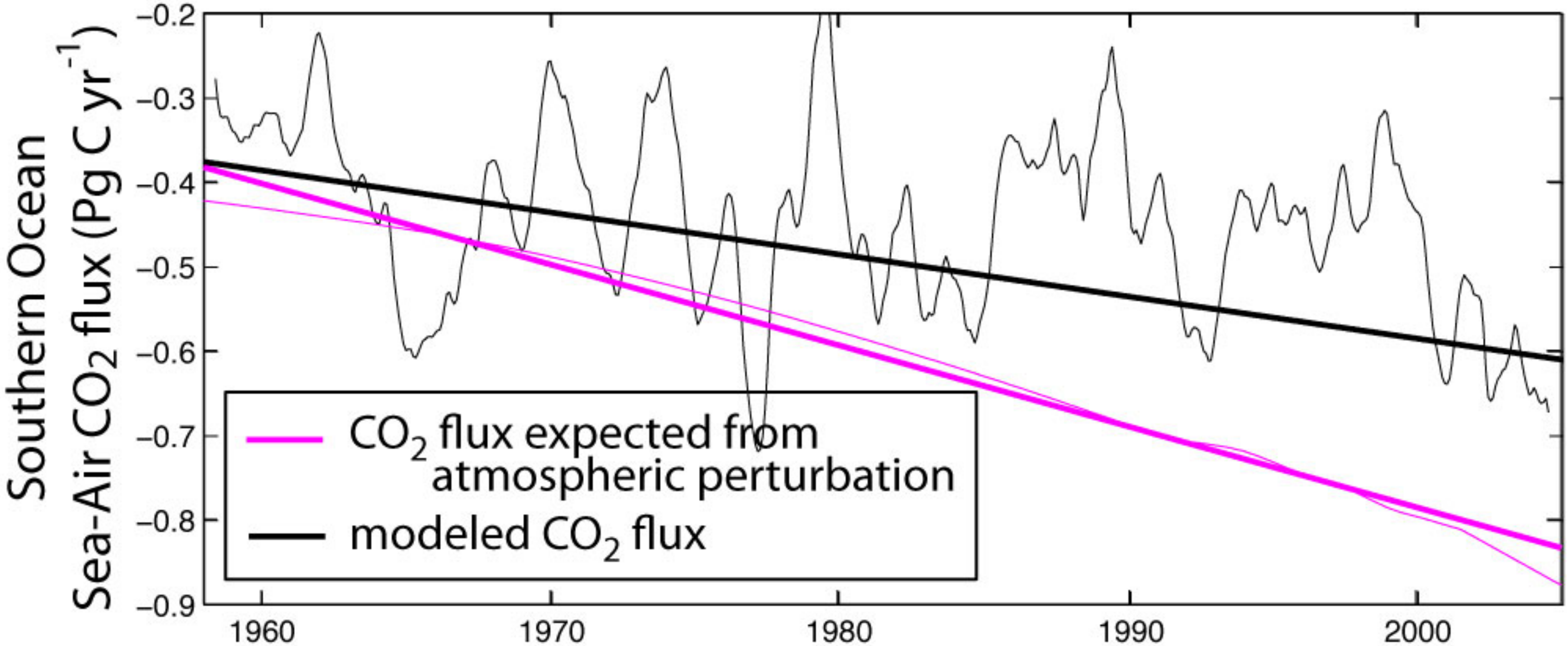


Historical evolution of CO_2 exchange





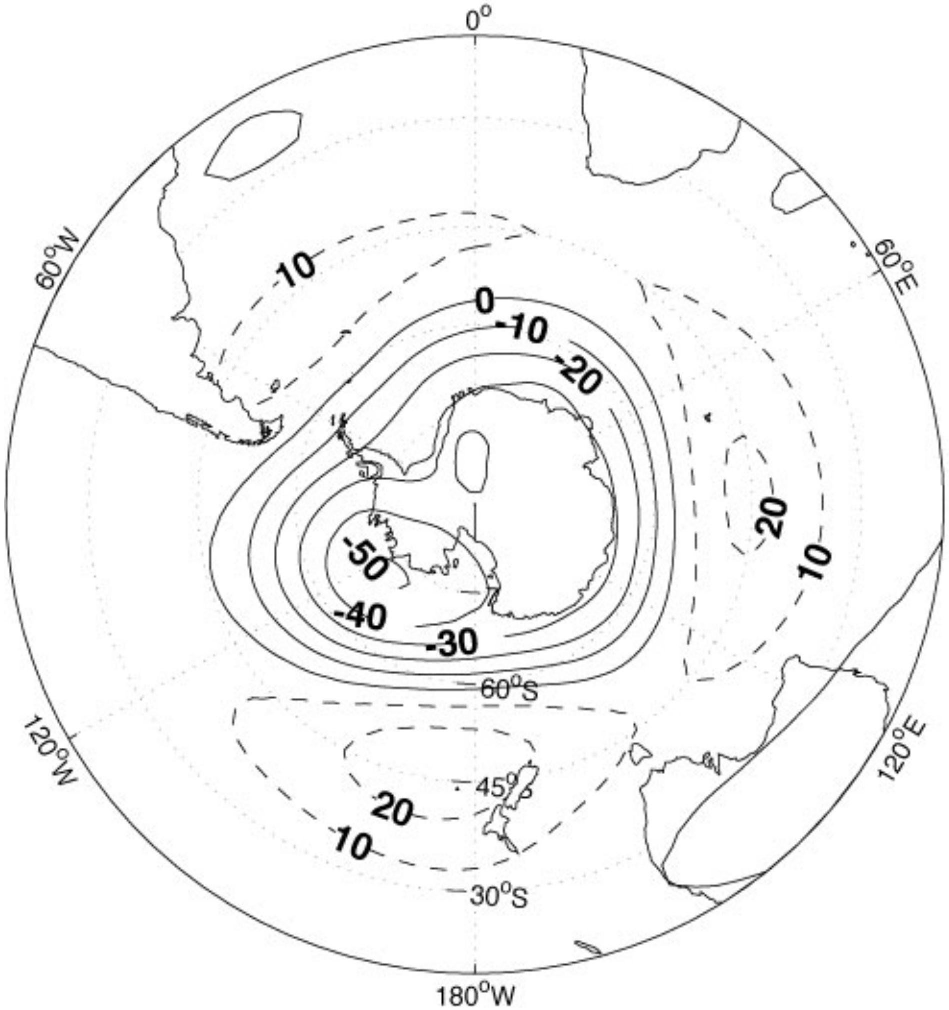
Variability and trends in CO_2



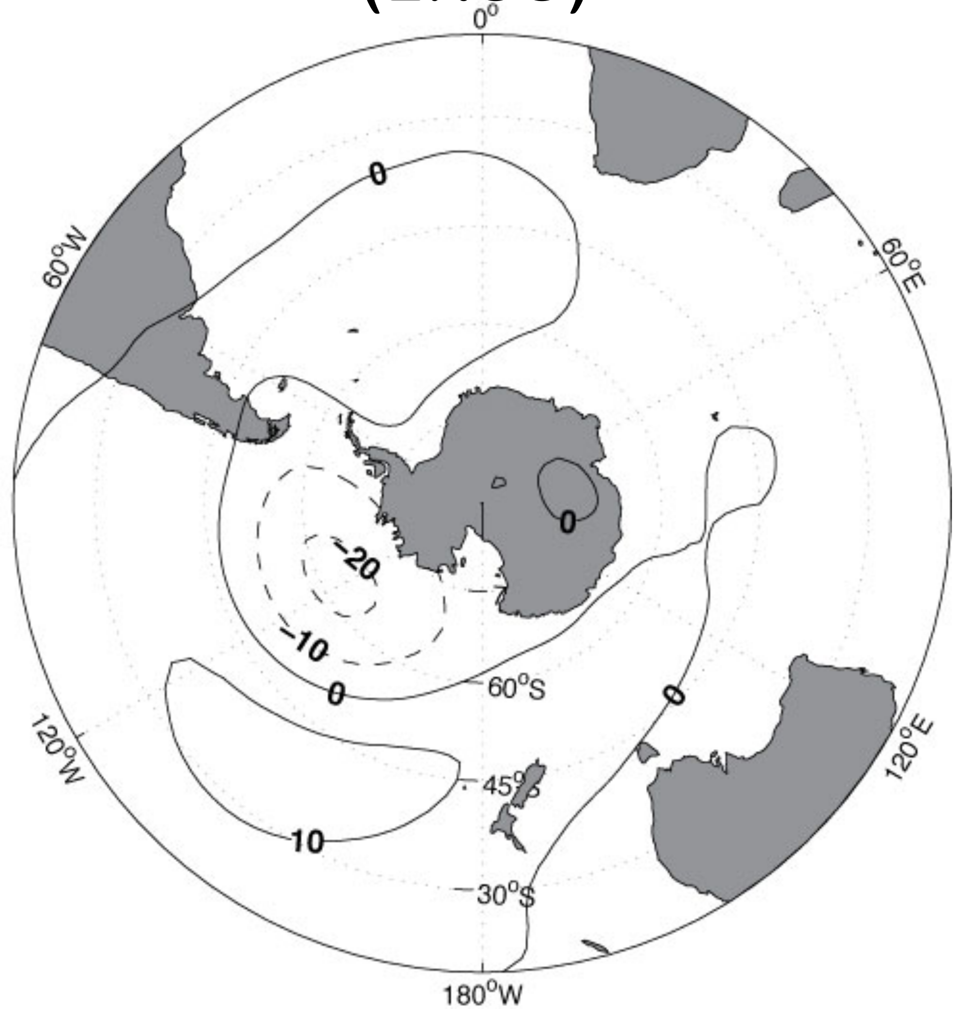
Lovenduski et al. (2008)

Modes of climate variability

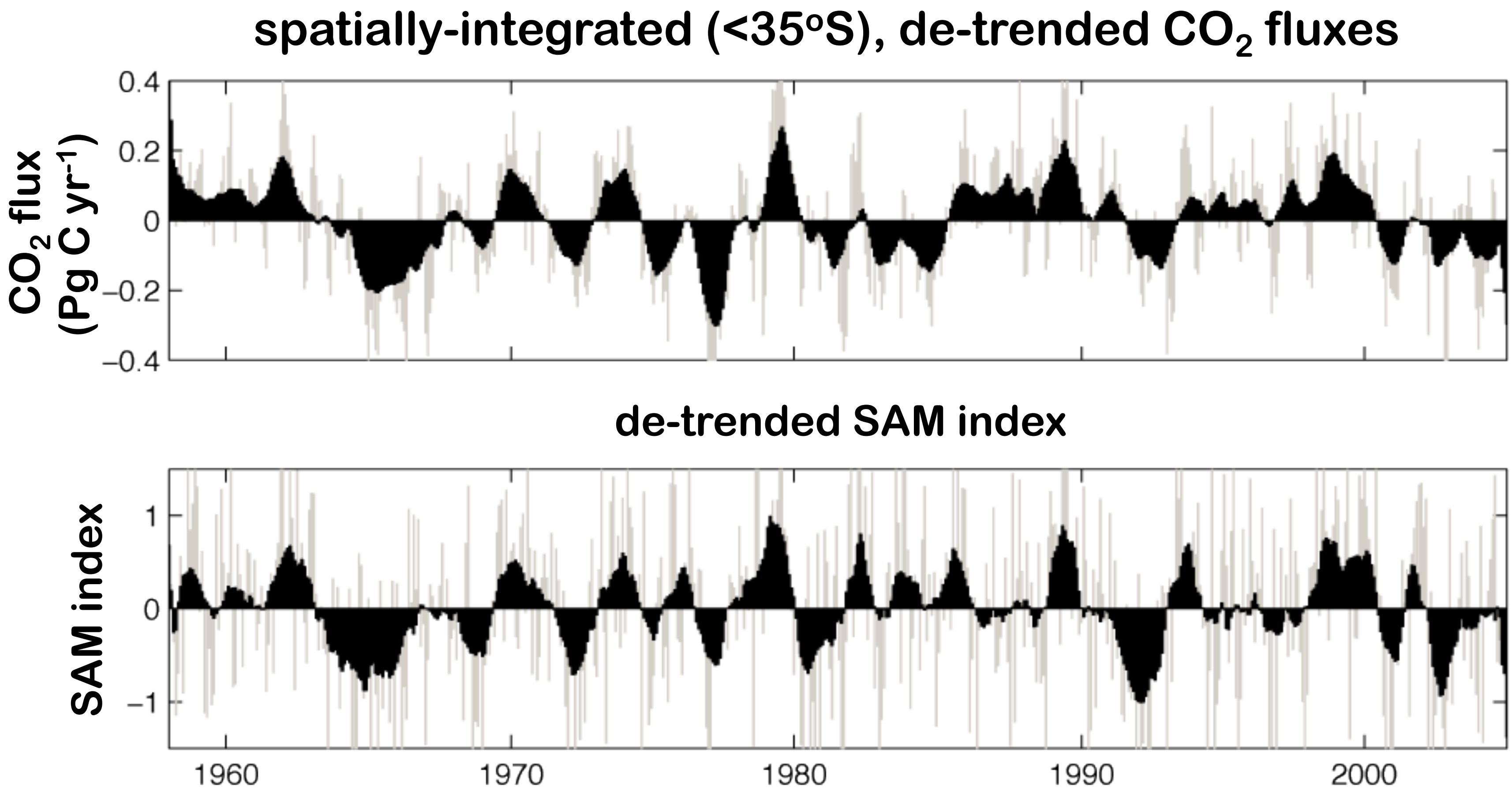
Southern Annular Mode (SAM)



El Niño – Southern Oscillation (ENSO)

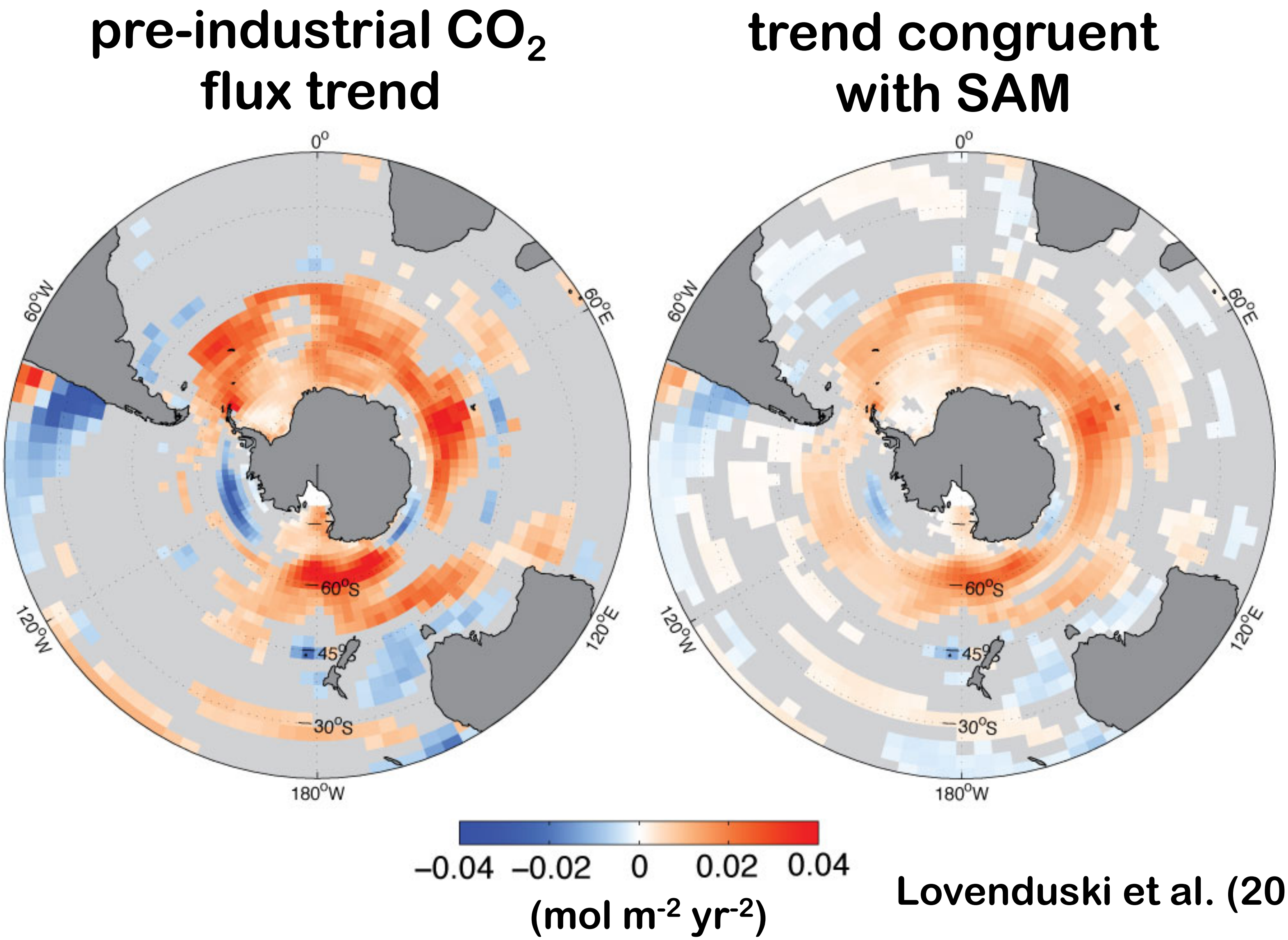


SAM drives CO_2 flux variability



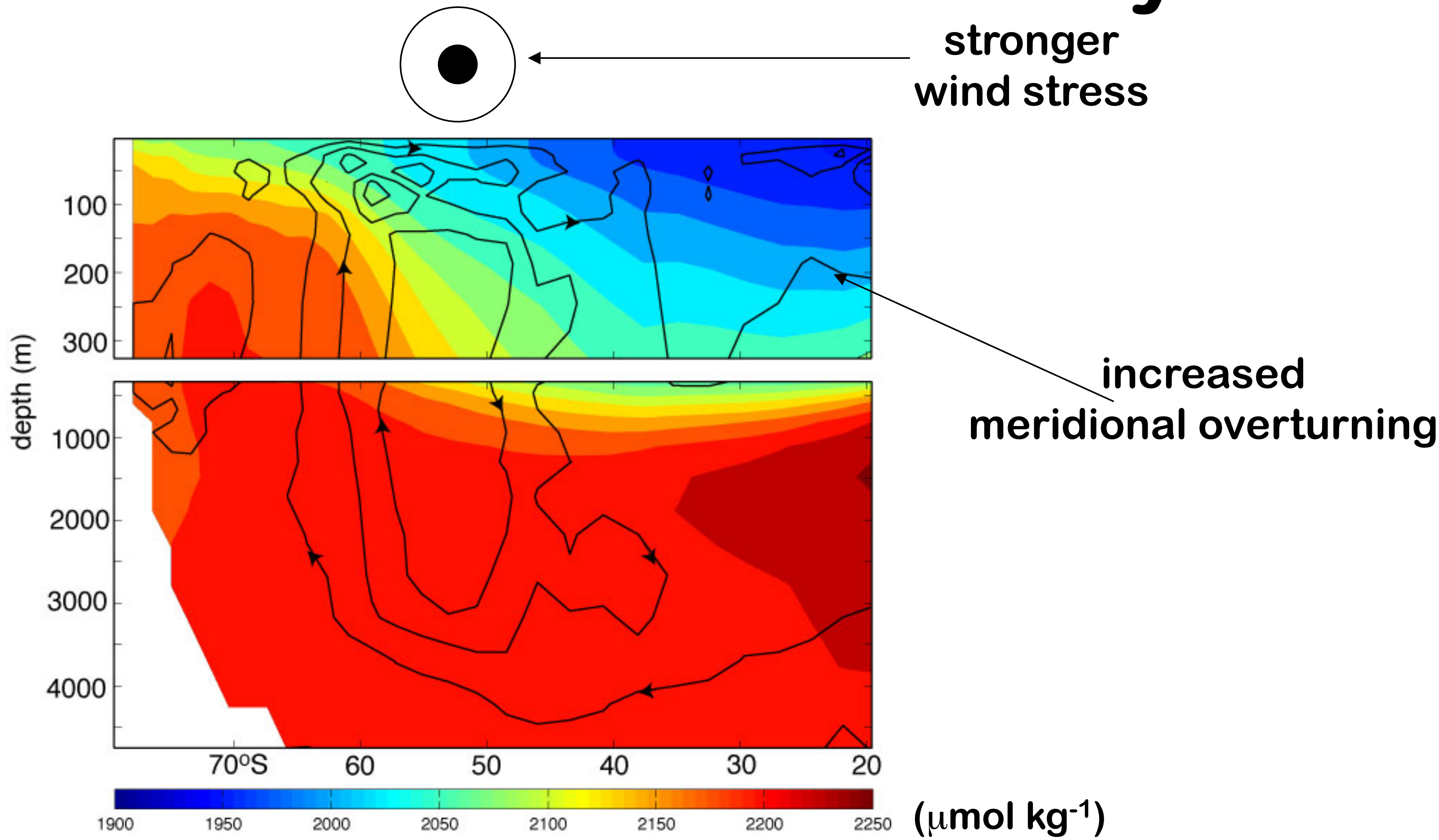
Lovenduski et al. (2007)

SAM drives CO_2 flux trend



Lovenduski et al. (2008)

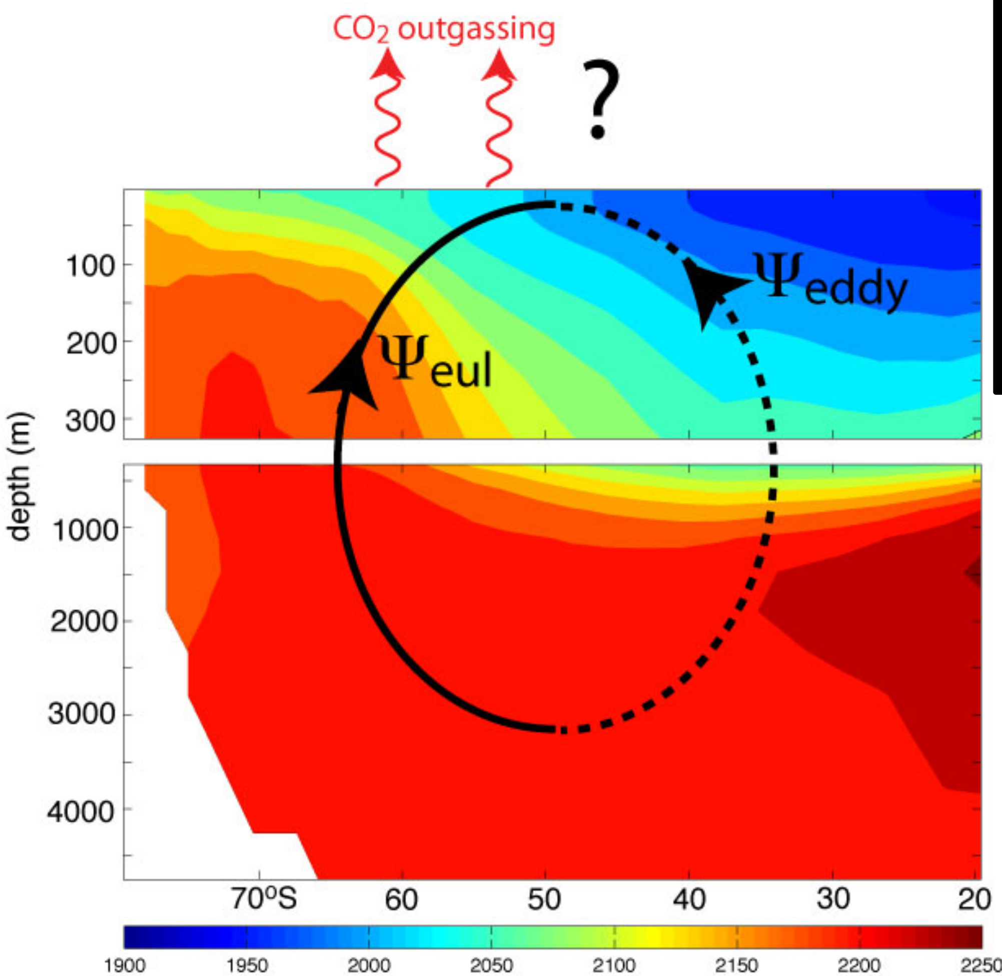
Causes of variability



zonal-mean dissolved inorganic carbon

Lovenduski et al. (2008)

The great eddy debate



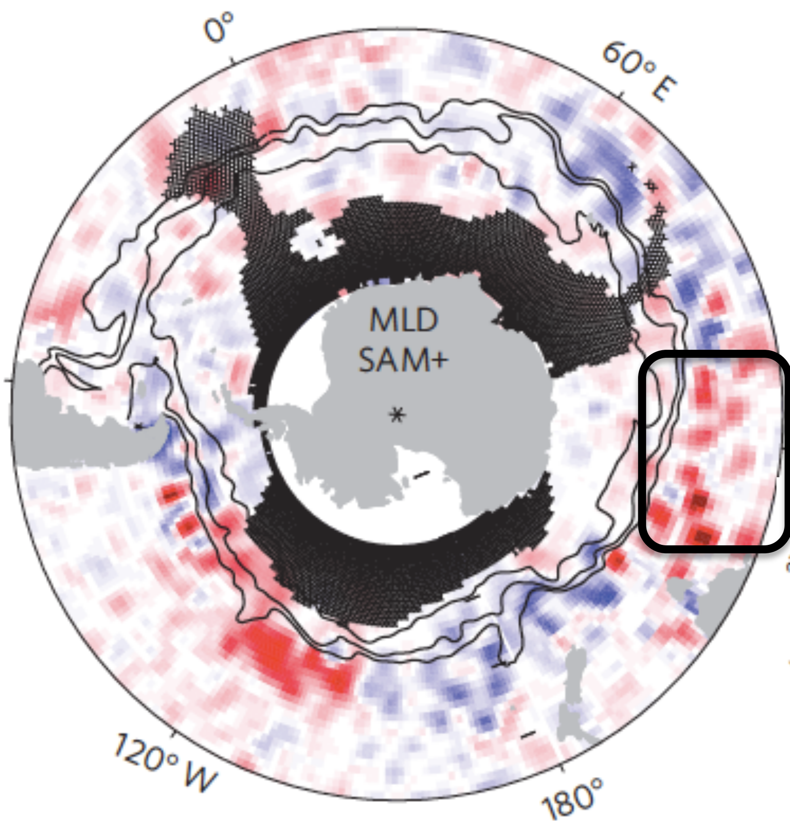
Can coarse-resolution ocean models simulate an appropriate response to increasing Southern Hemisphere winds?

a few references ...

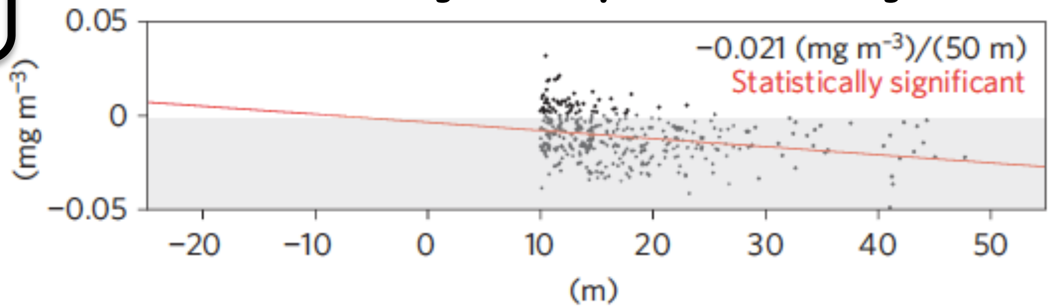
Hallberg and Gnadadesikan (2006)
Boning et al. (2008)
Hogg et al. (2008)
Screen et al. (2009)
Farneti et al. (2010)
Spence et al. (2010)
Farneti and Gent (2011)
Gent and Danabasoglu (in press)

SAM drives ecosystem variability

Mixed Layer Depth anomaly
(+ SAM)



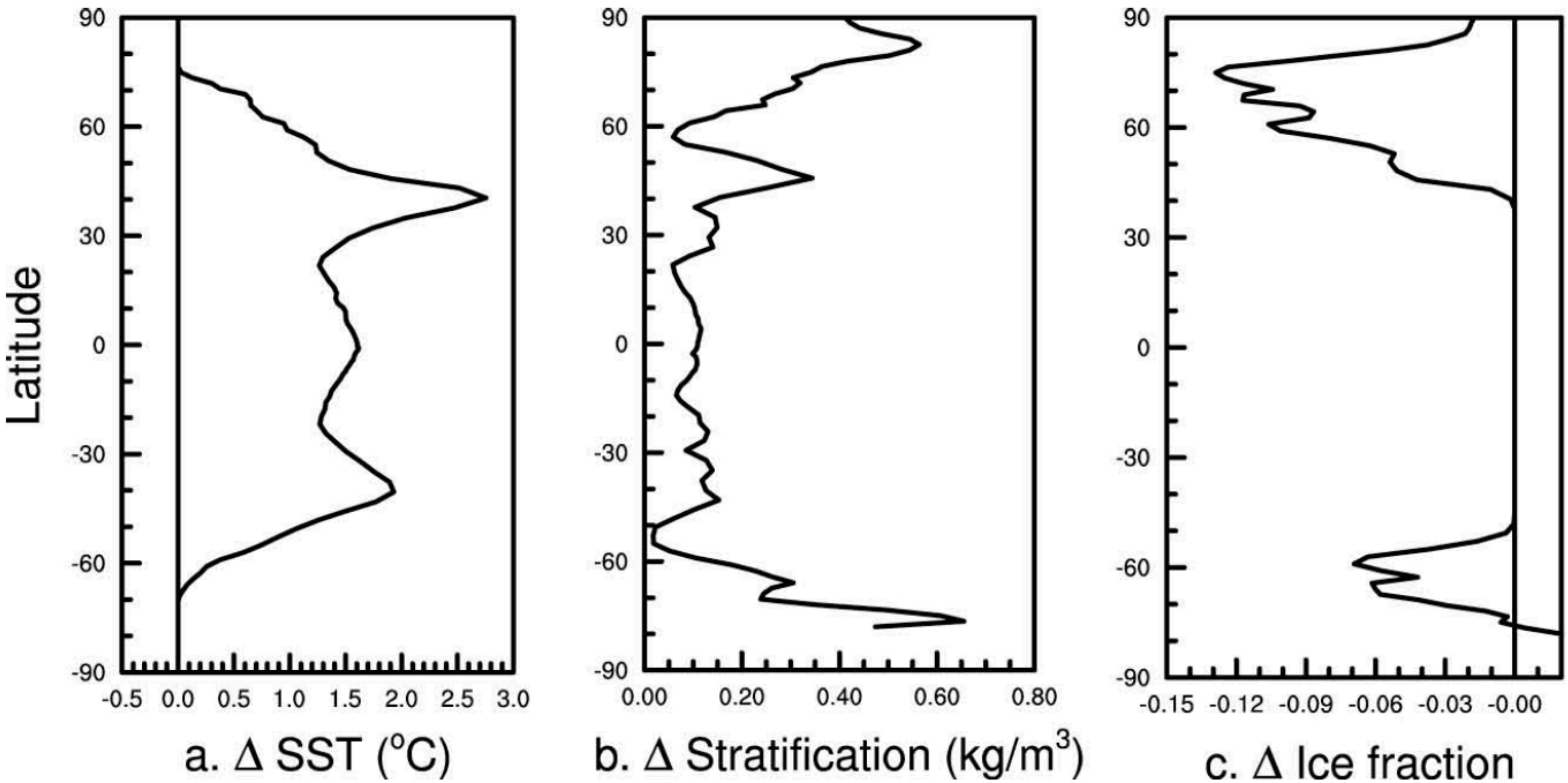
surface chlorophyll anomaly vs. mixed layer depth anomaly



Sallée et al. (2010)

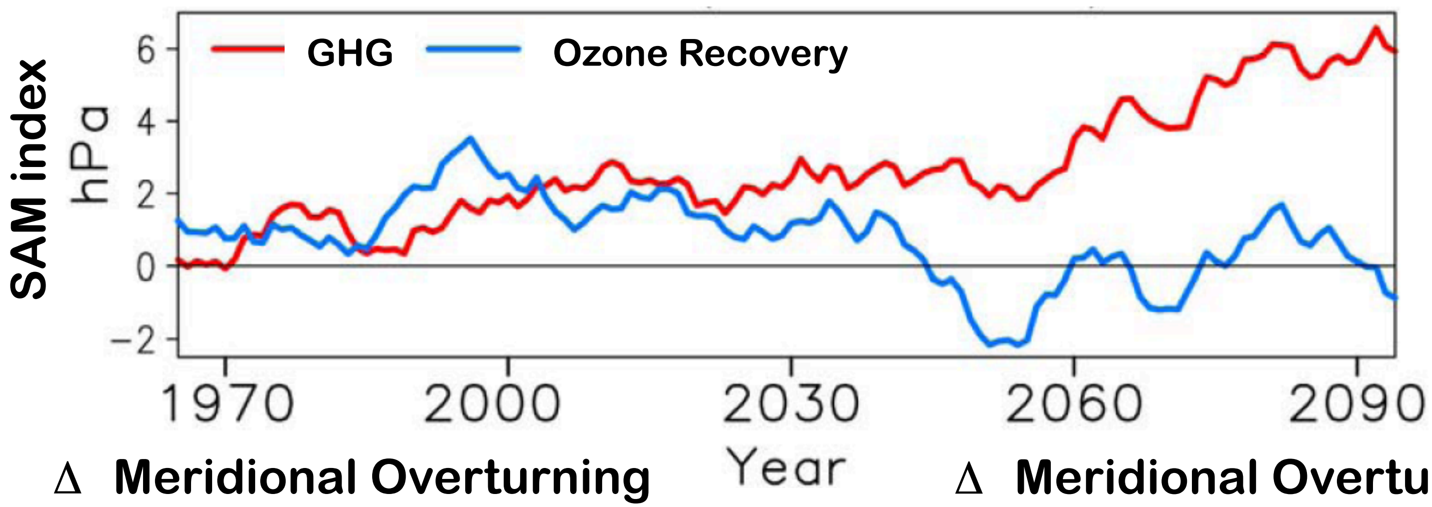
Part 3: Future Changes

Stratification

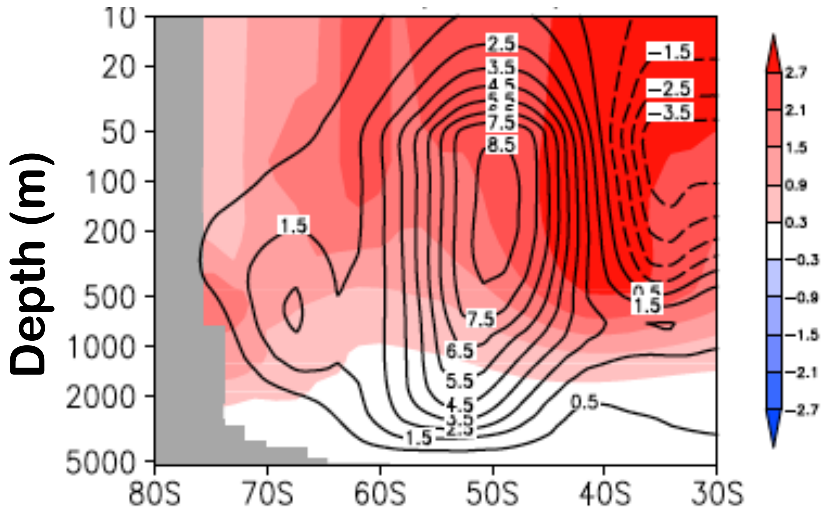


Marinov et al. (2010)

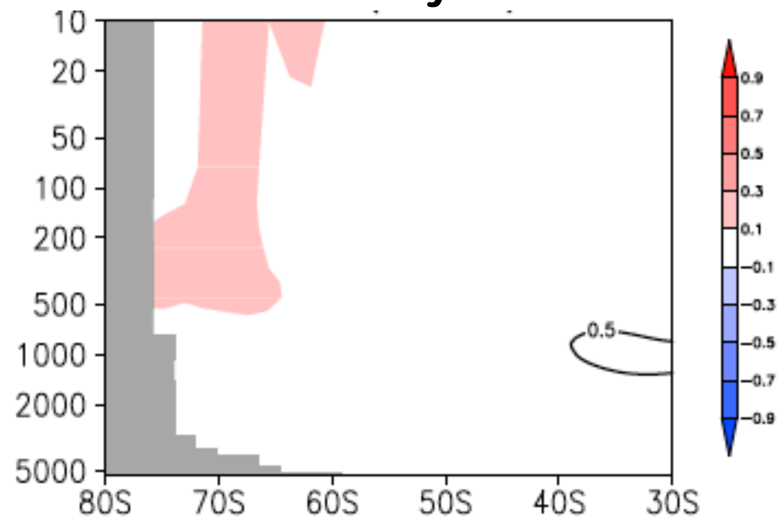
Wind-driven circulation



Δ Meridional Overturning
GHG simulation



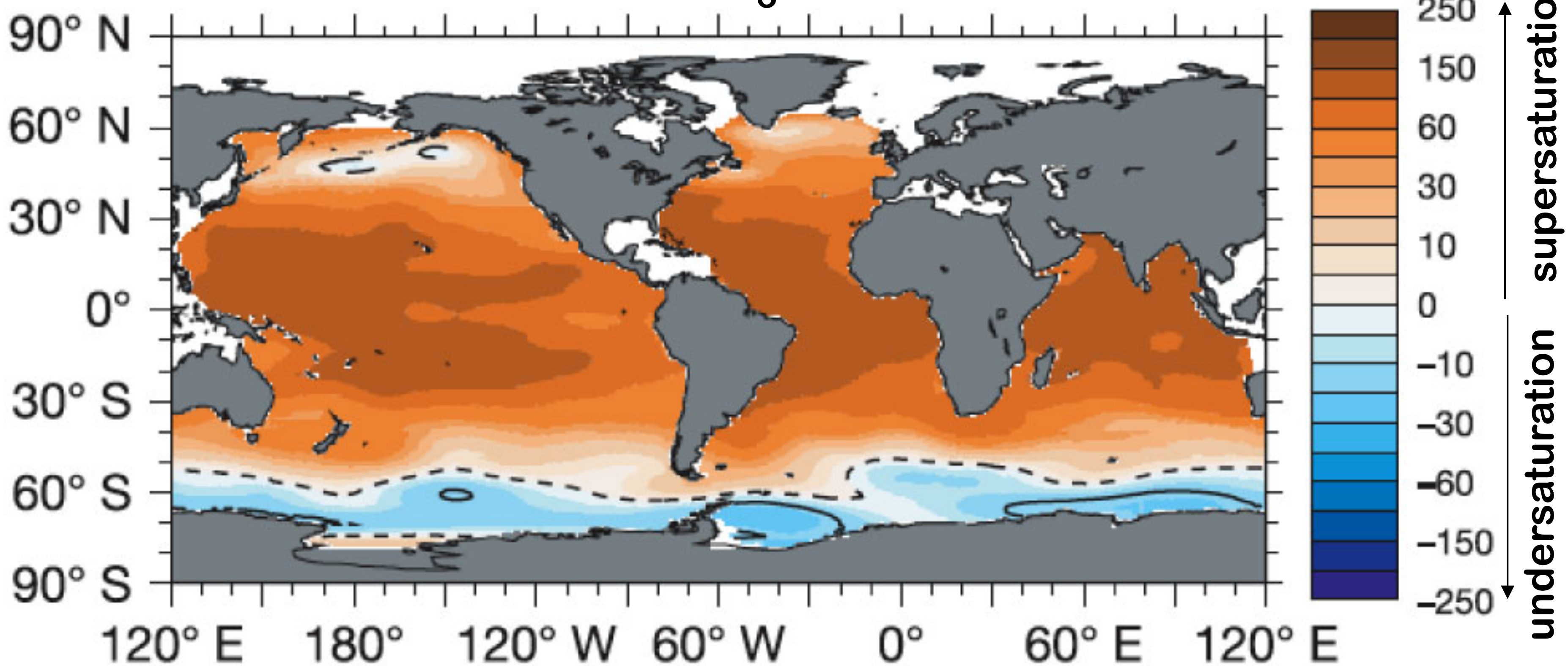
Δ Meridional Overturning
Ozone Recovery simulation



Sigmond et al. (2011)

Acidification

surface ΔCO_3^{2-} in 2100



$$\Delta CO_3^{2-} = [CO_3^{2-}] - [CO_3^{2-}]_{sat}$$

Orr et al. (2005)

The issues that plague us…

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

3. What is the role of eddies in CO_2 uptake and transport?

The issues that plague us…

Variability

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

The issues that plague us…

Future Changes

1. Stratification of the Southern Ocean
    1. Impacts on carbon storage
    2. Impacts on 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?

The End!