

Carbon in the Southern Ocean: Known knowns and known unknowns

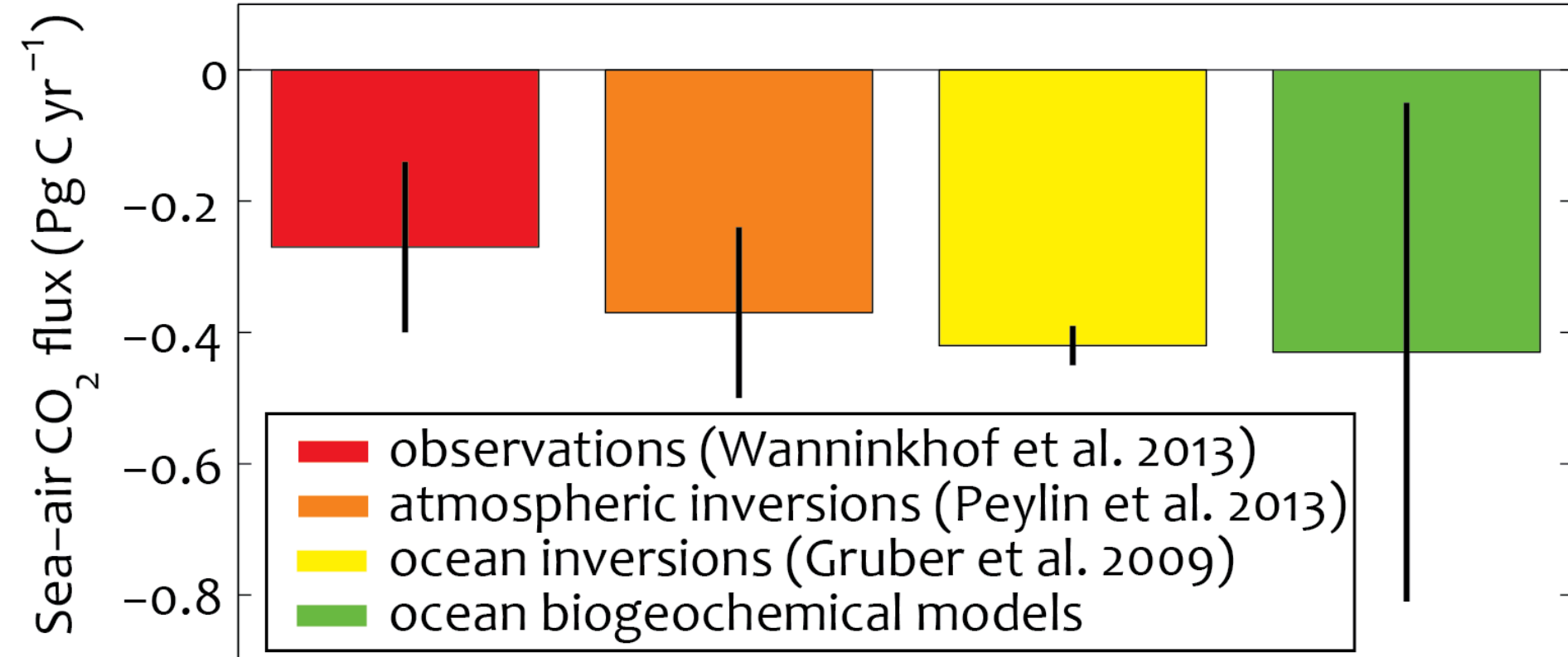
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Part I:
Known knowns

Southern Ocean is a sink for atmospheric CO₂

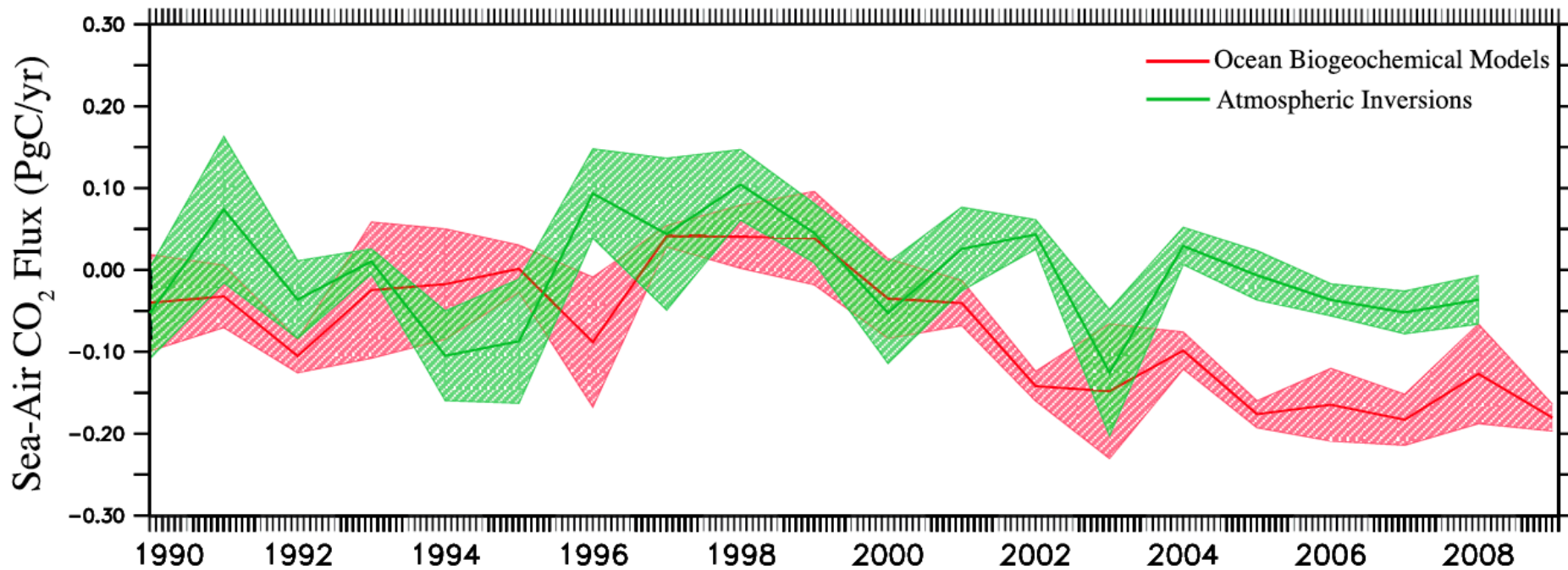
Median annual sea-air CO₂ flux, 1990-2009, 44°S-75°S



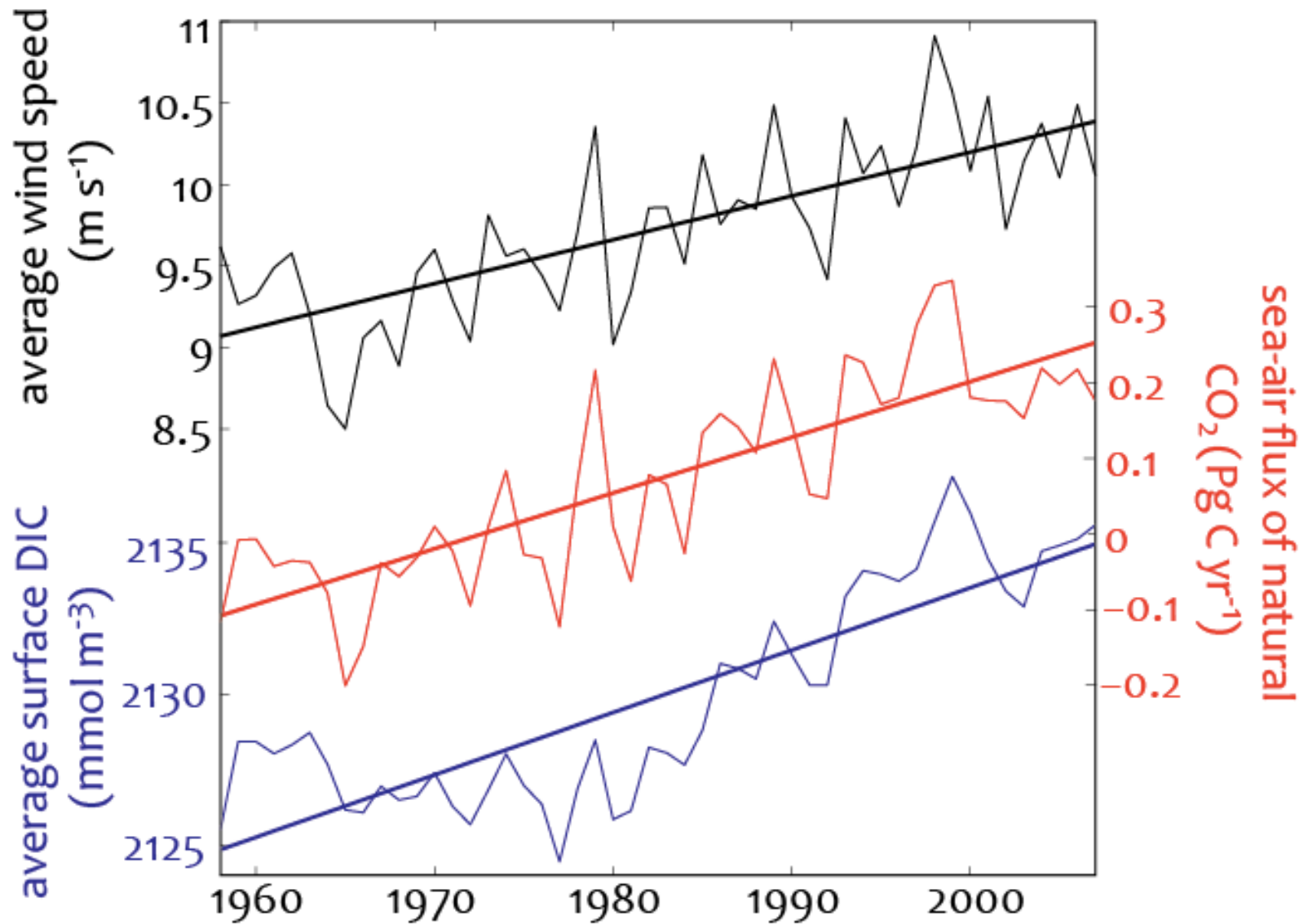
data from Lenton et al. (2013)

Southern Ocean has large CO₂ flux variability

Integrated sea-air CO₂ flux, 44°S-75°S



Wind drives natural CO₂ flux variability

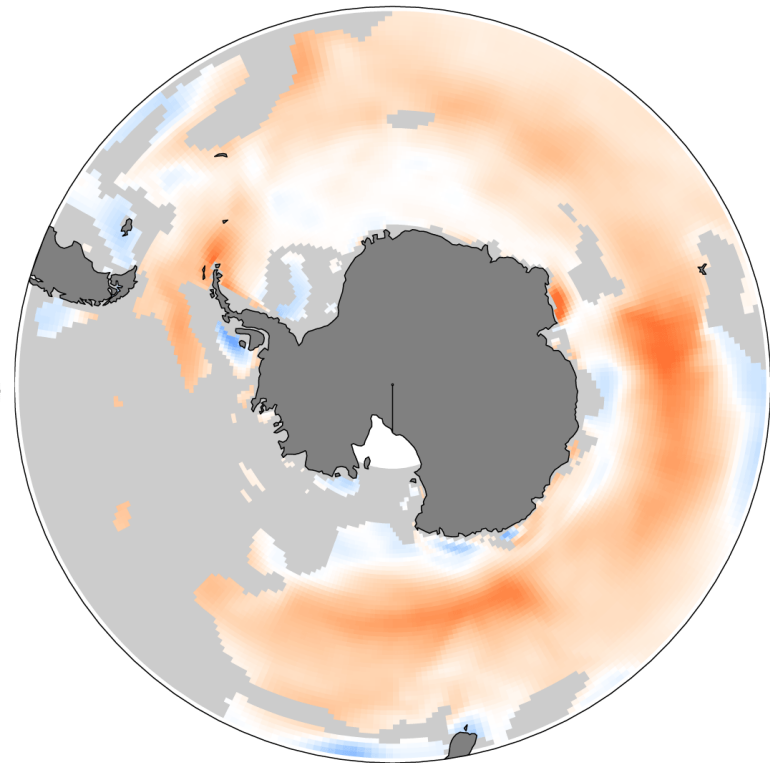
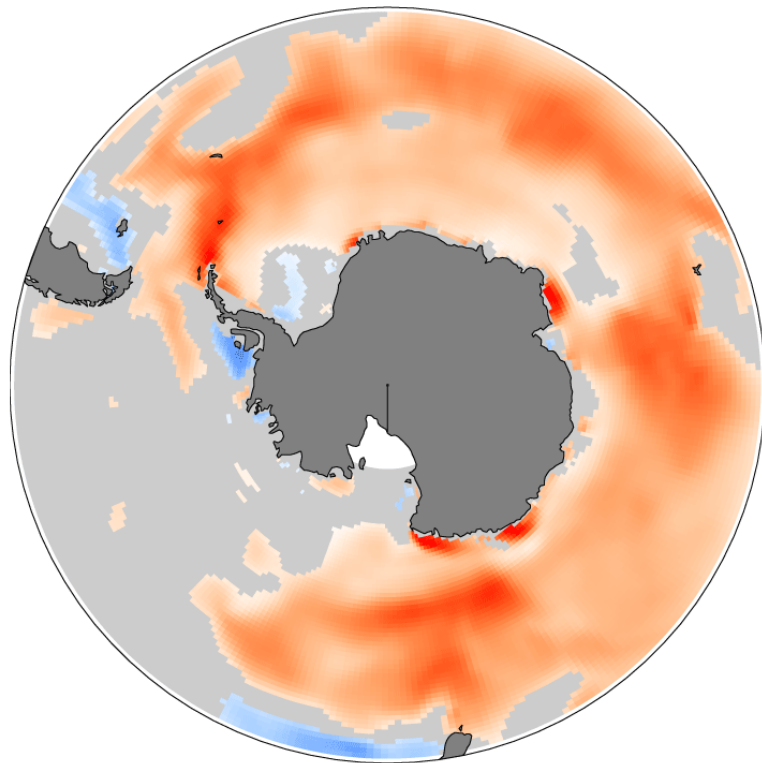


Lovenduski et al. (2013)

Wind drives natural CO₂ flux trend

Linear trend
1958-2007

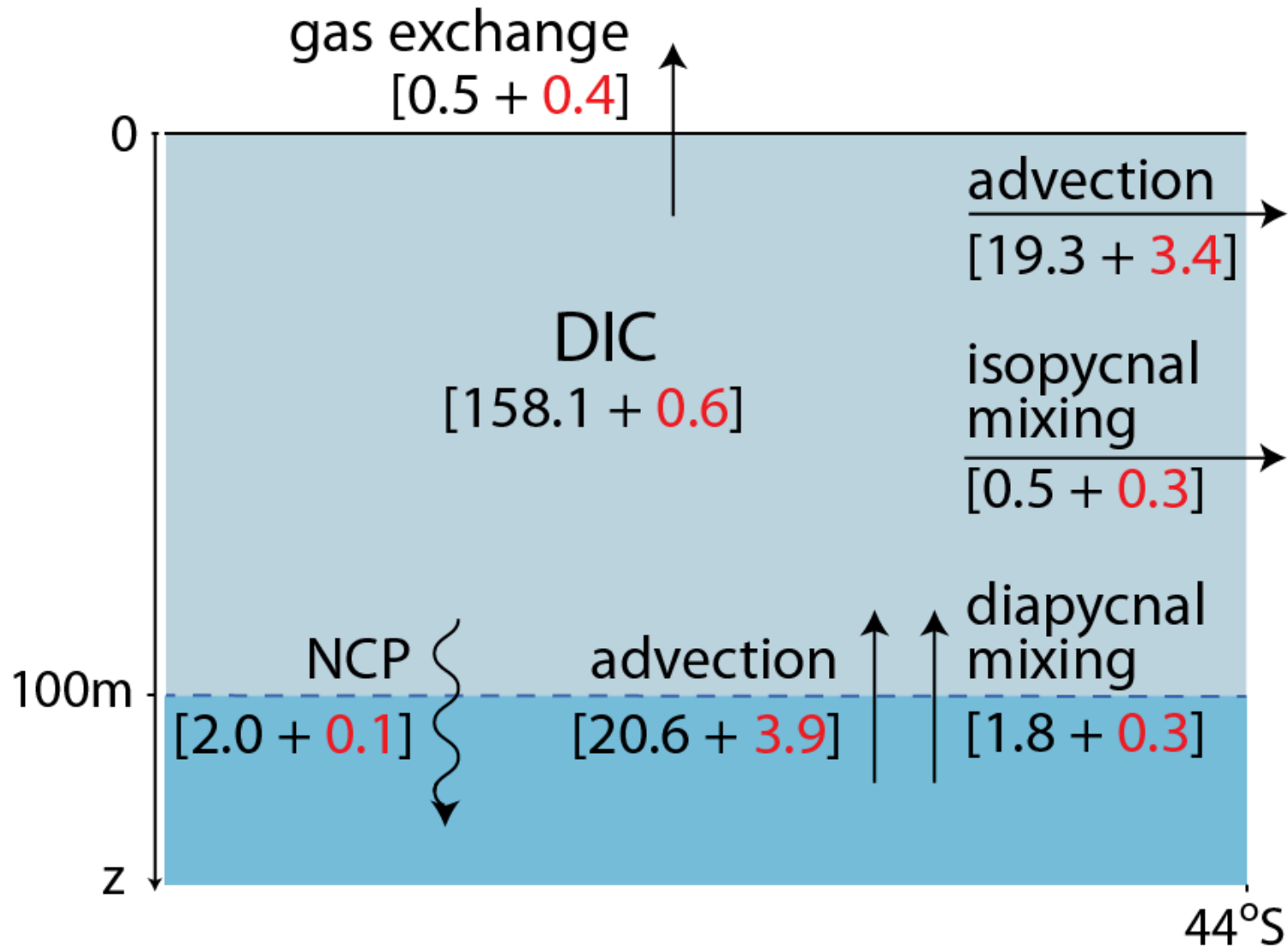
Trend congruent
with wind



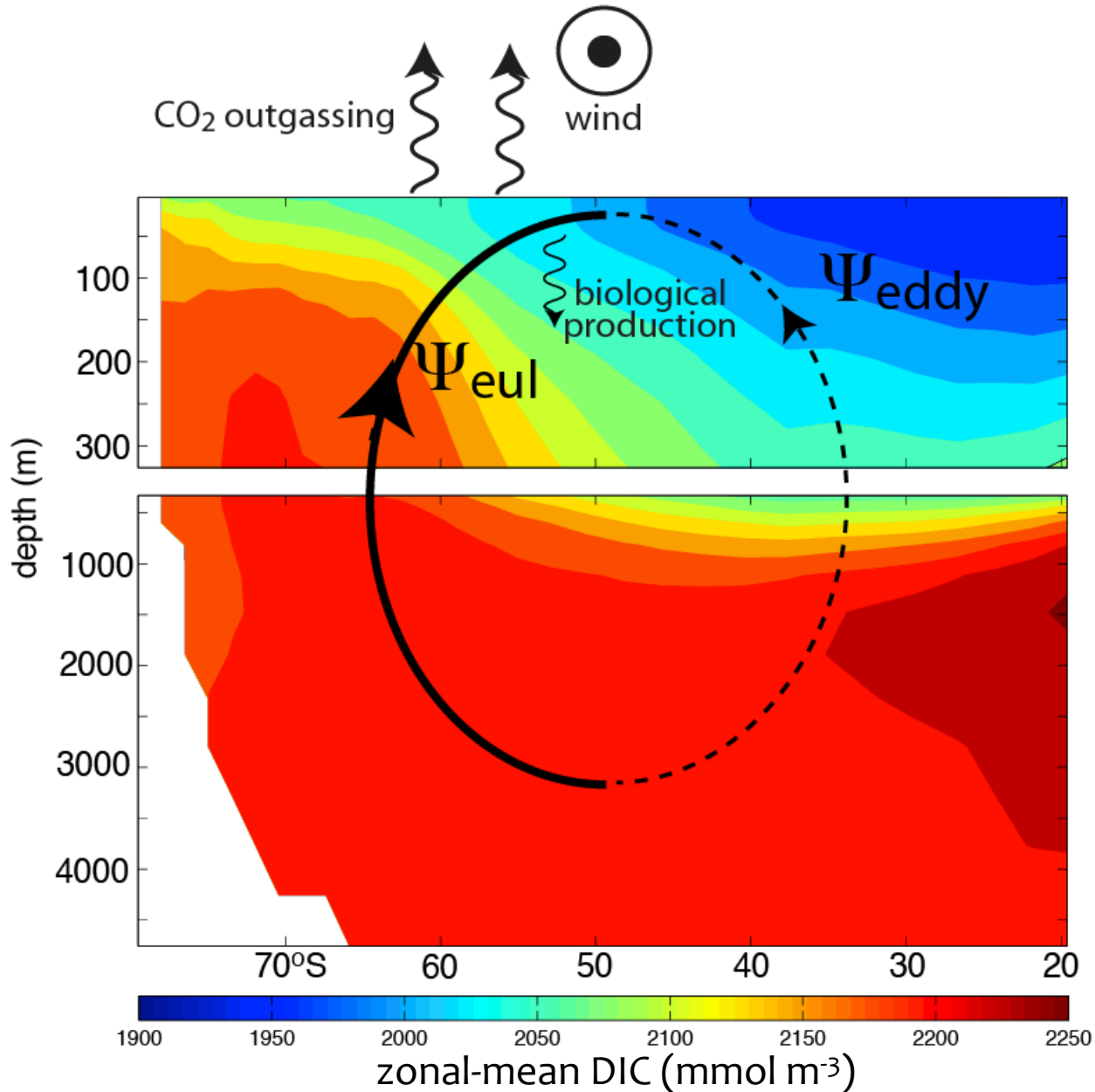
-0.05 0 0.05
(mol C m⁻² yr⁻²)

Lovenduski et al. (2013)

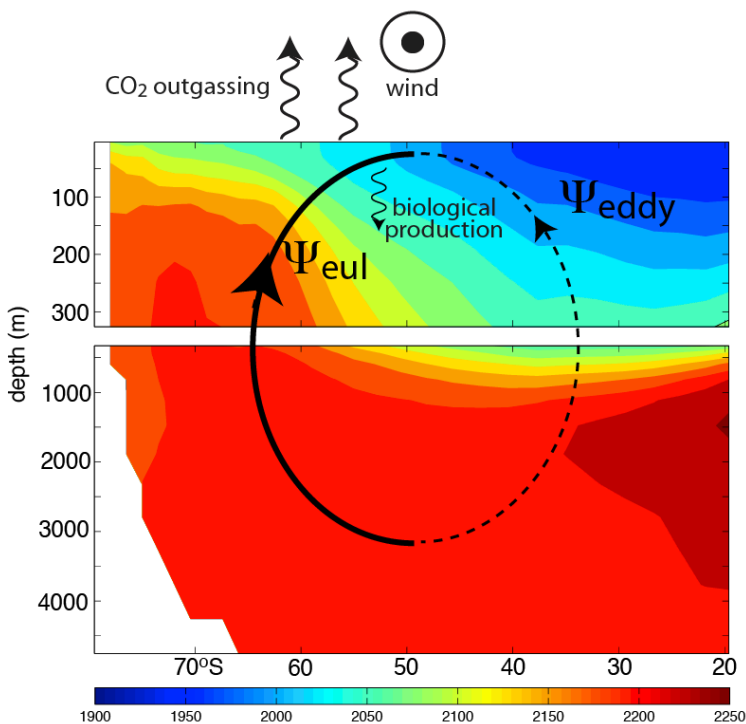
Stronger wind = higher surface DIC



Mechanism



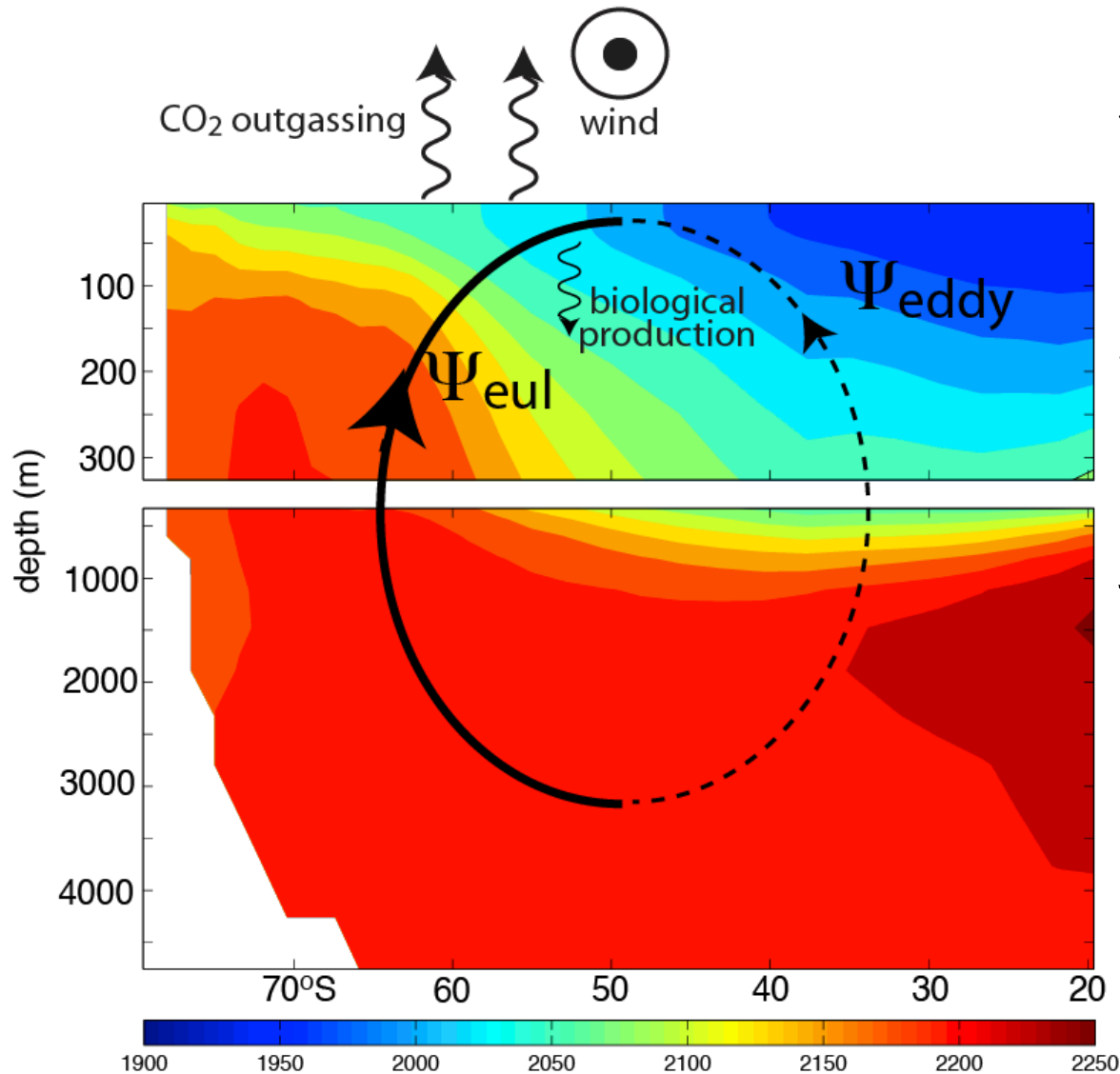
Corroborating model results



Model	Reference
Bern3D	Tschumi et al. 2008
CCSM/CESM	Lovenduski et al. 2007 Wang and Moore 2012 Lovenduski et al. 2013
CSIRO	Lenton et al. 2007
LOVECLIM	Menviel et al. 2008
MITgcm	Lovenduski and Ito 2009
OPA	LeQuéré et al. 2007
UVic	Zickfeld et al. 2007

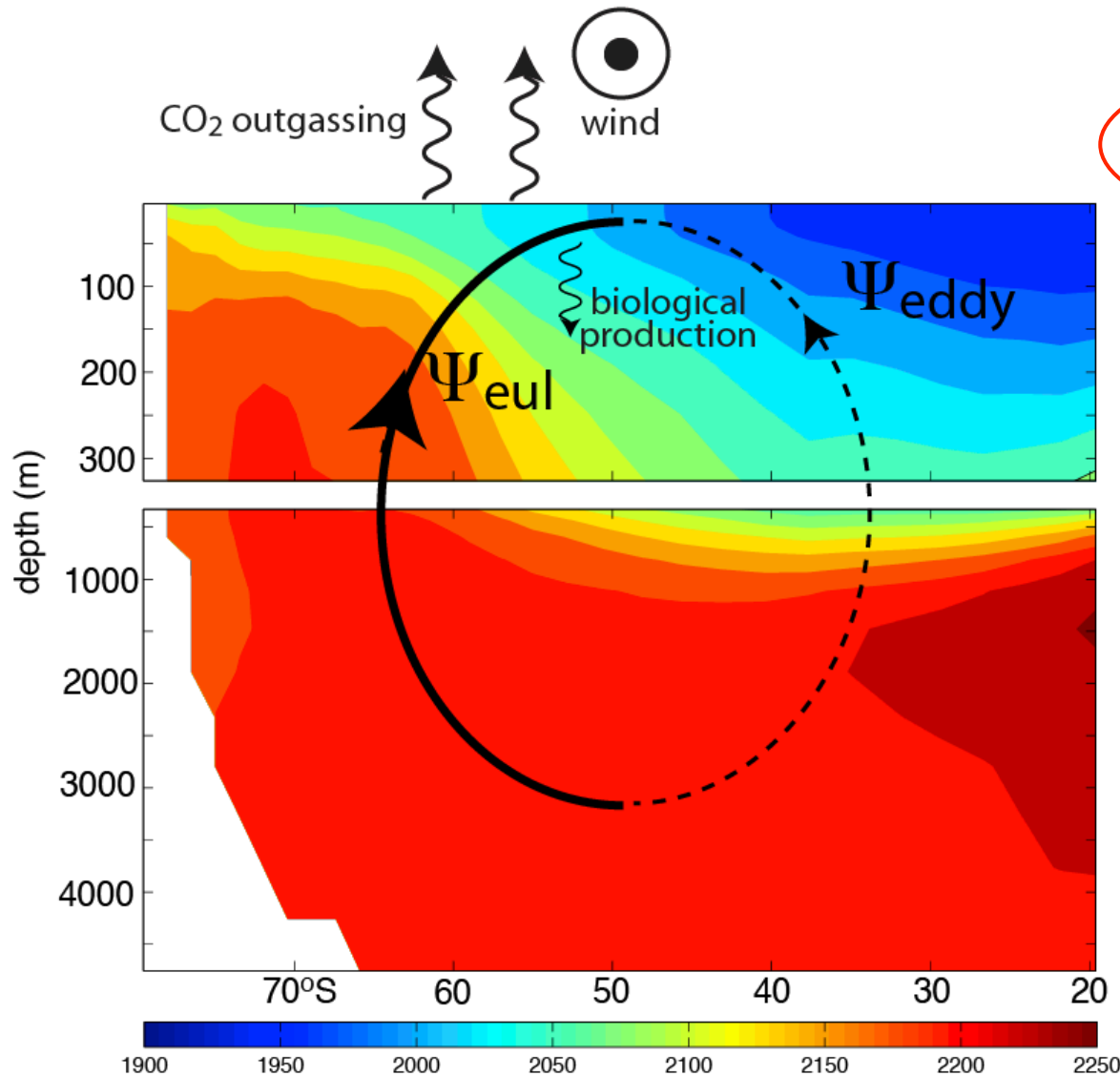
Part II:
Known unknowns

Observing the mechanism



1. Is the model-predicted CO₂ flux trend real?
2. Has meridional overturning increased?
3. Has biological production changed?

Observing the mechanism



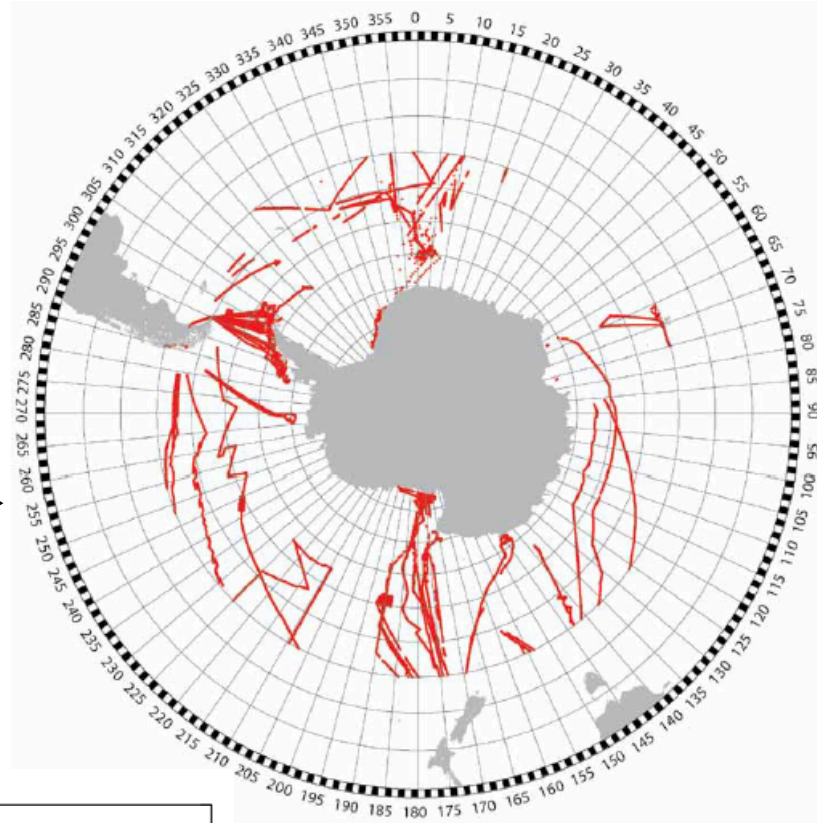
1. Is the model-predicted CO₂ flux trend real?

2. Has meridional overturning increased?

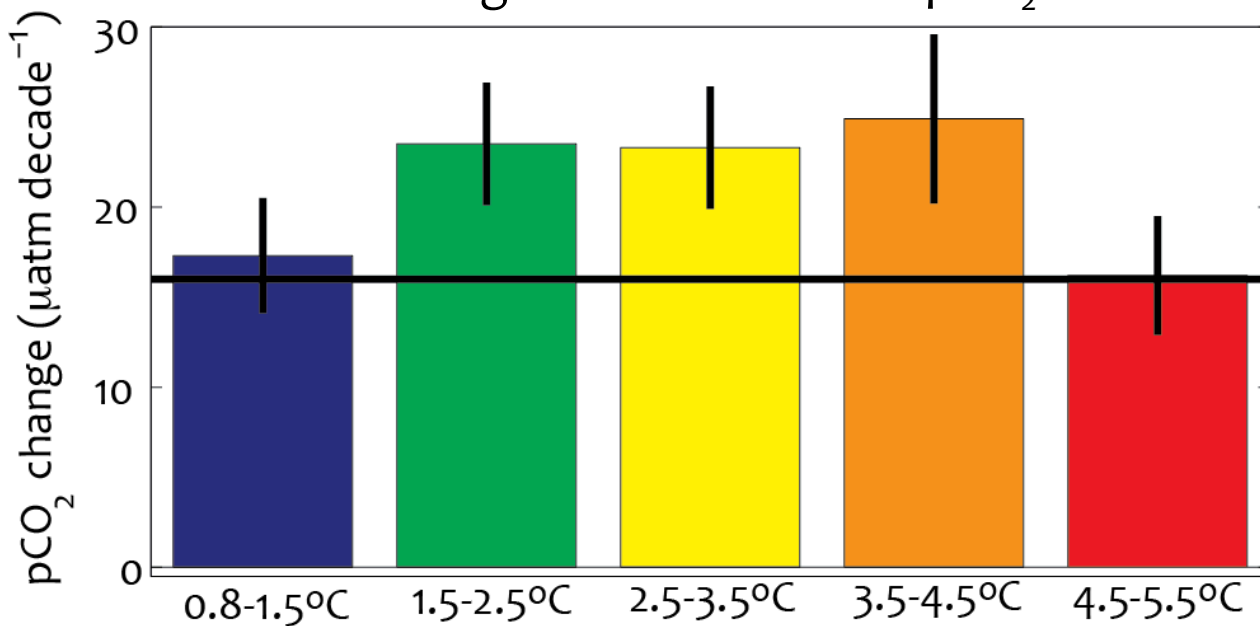
3. Has biological production changed?

Observed wintertime pCO₂ changes 1986-2010

Wintertime data locations →



Change in surface ocean pCO₂



Change in
atmospheric
pCO₂

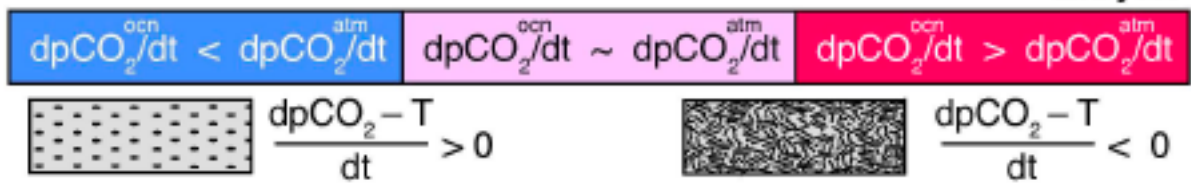
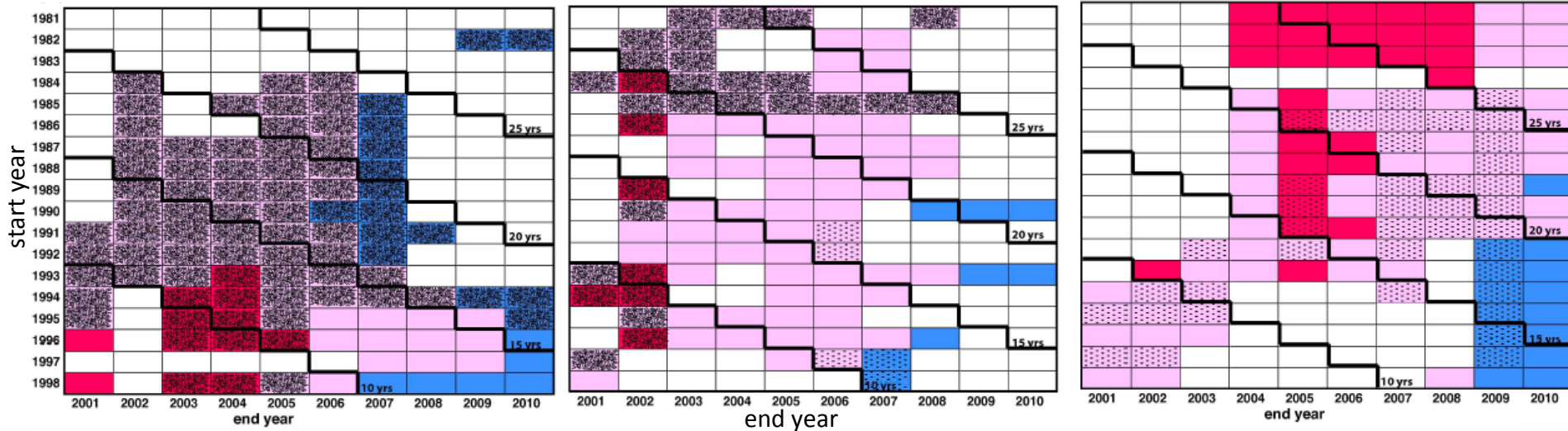
data from
Takahashi et al. (2012)

Trend in $p\text{CO}_2^{\text{oc}}$ vs. $p\text{CO}_2^{\text{atm}}$ trend

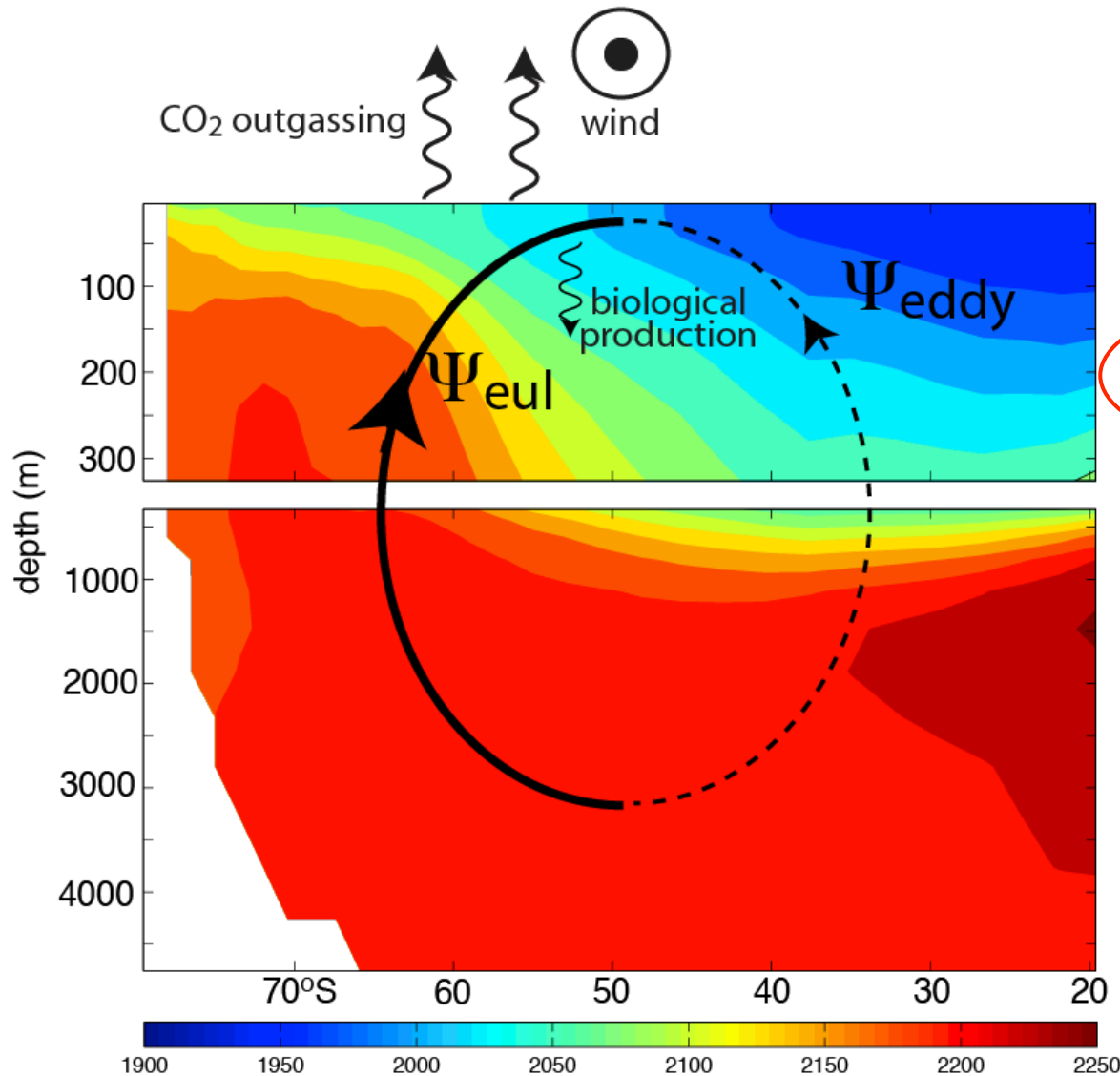
Antarctic Zone

Polar Frontal Zone

Subantarctic Zone



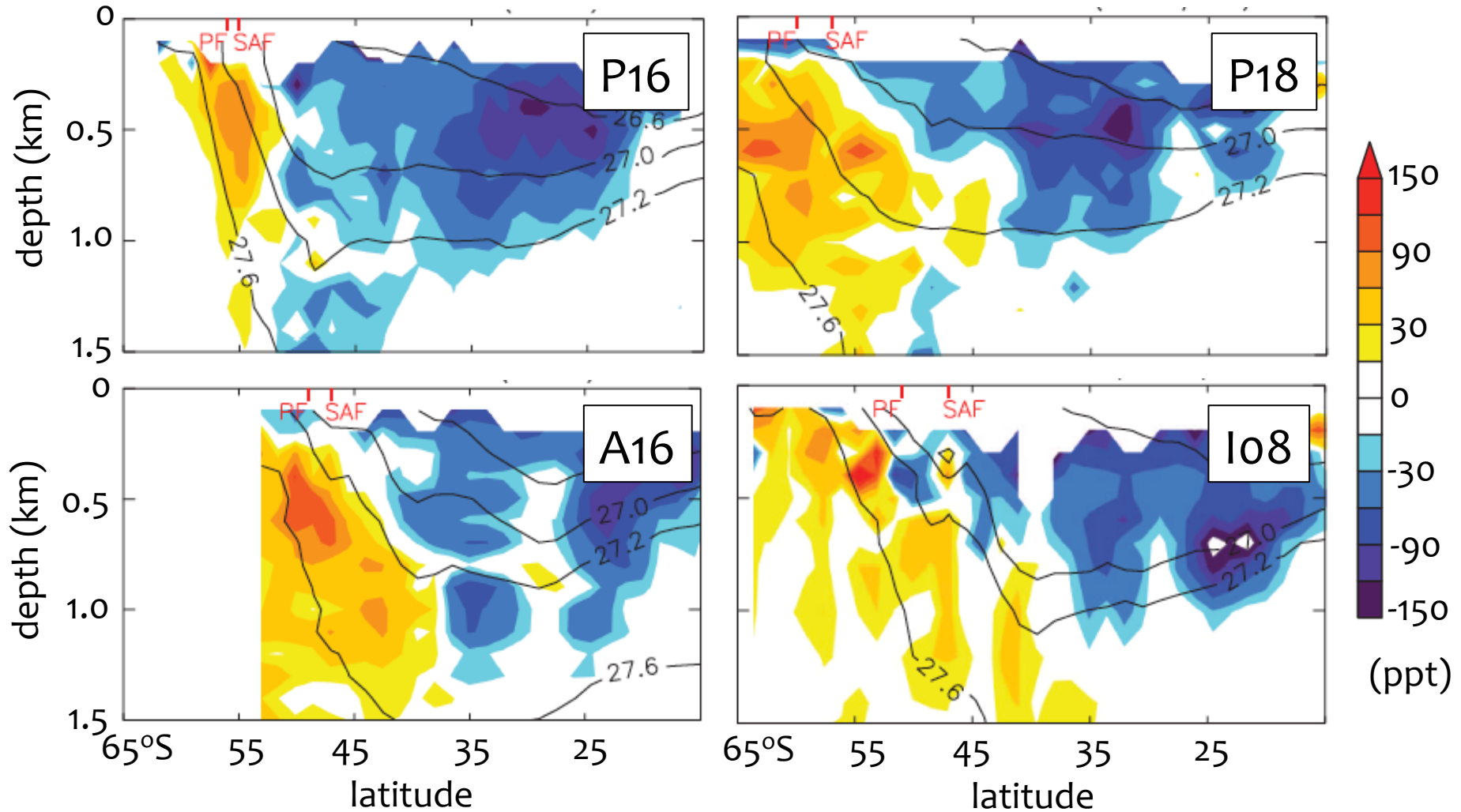
Observing the mechanism



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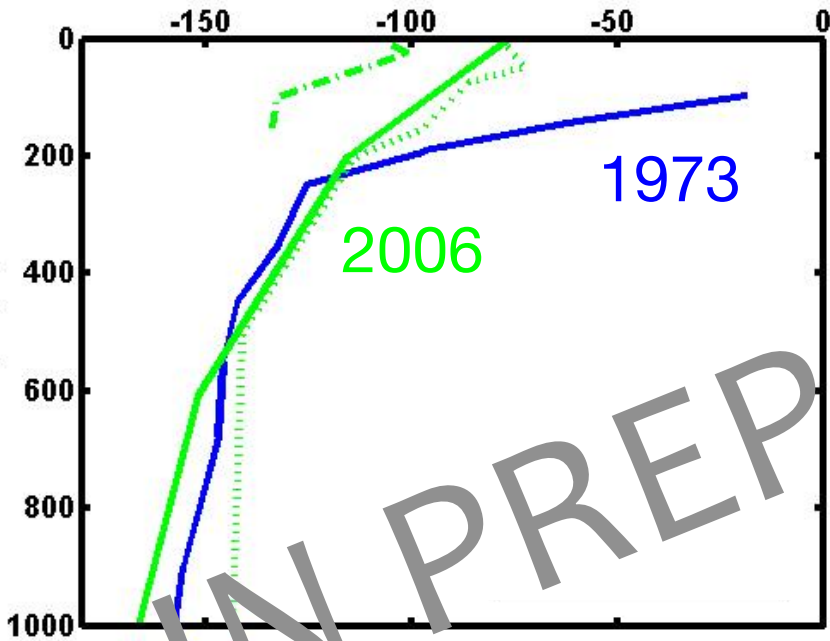
CFC-12 changes

Change in pCFC-12, early 1990's to late 2000's

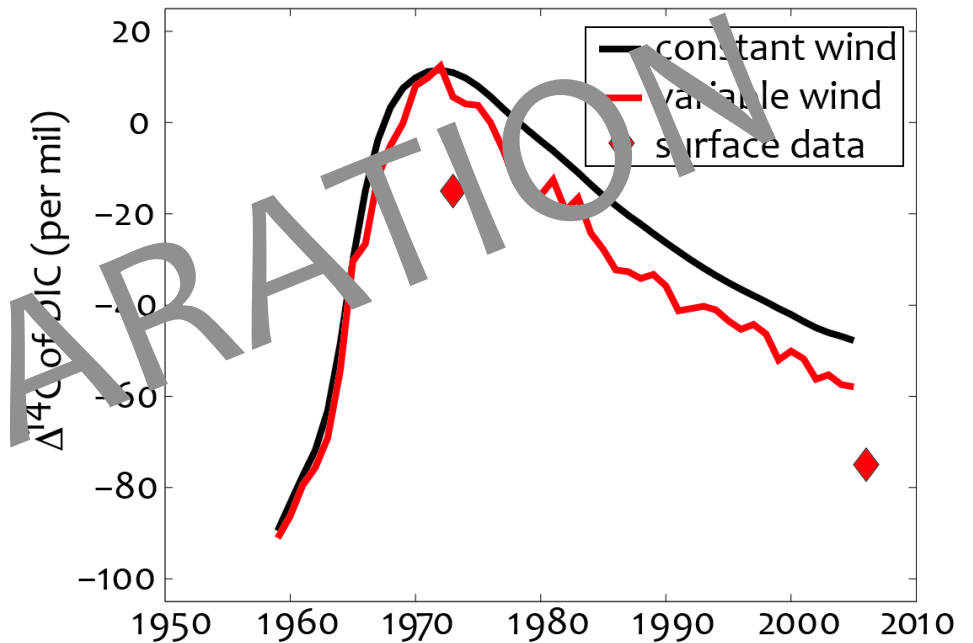


$\Delta^{14}\text{C}$ changes in Drake Passage

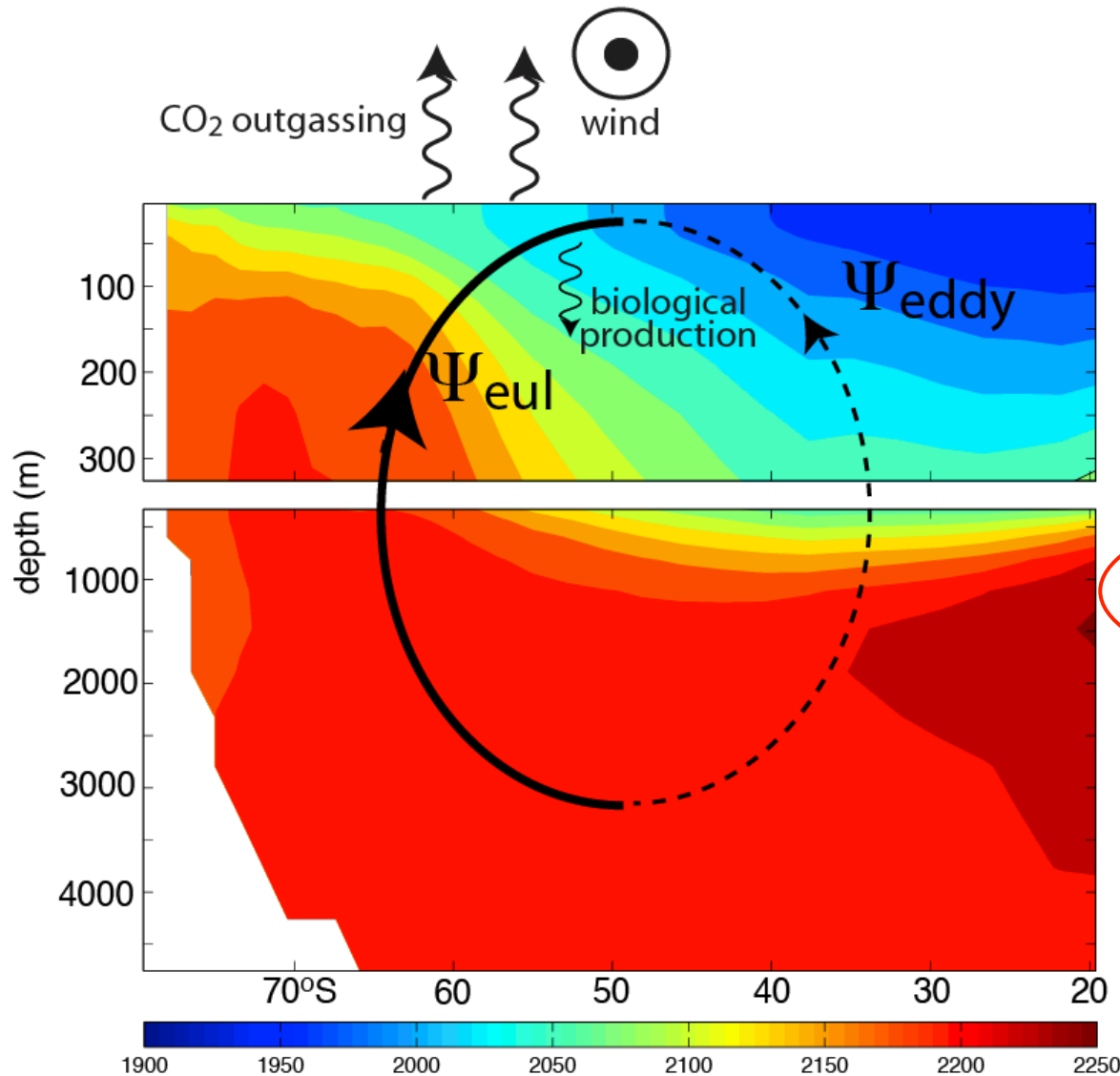
Observed change in $\Delta^{14}\text{C}$ (‰)



Modeled change in $\Delta^{14}\text{C}$ (‰)

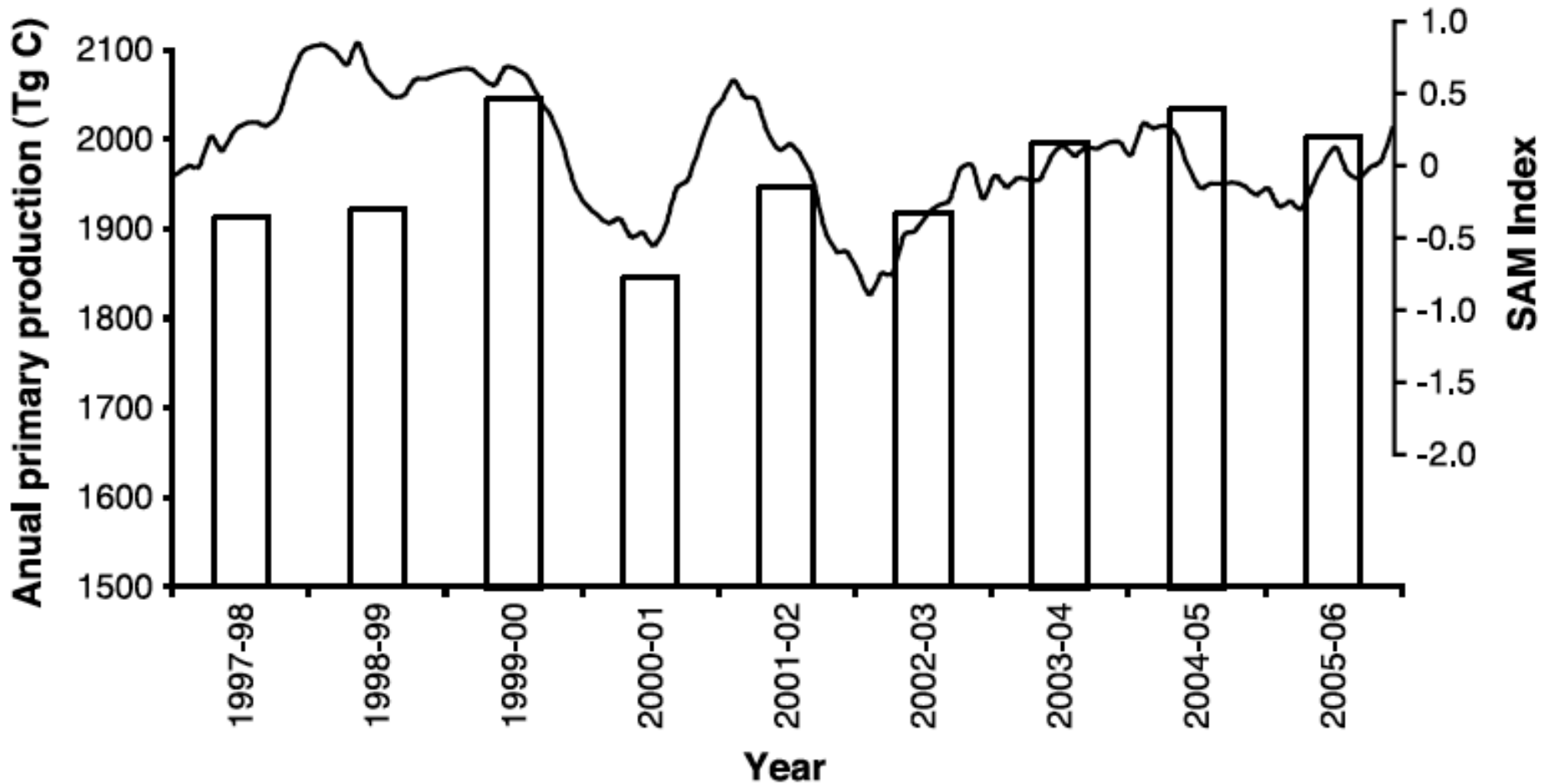


Observing the mechanism



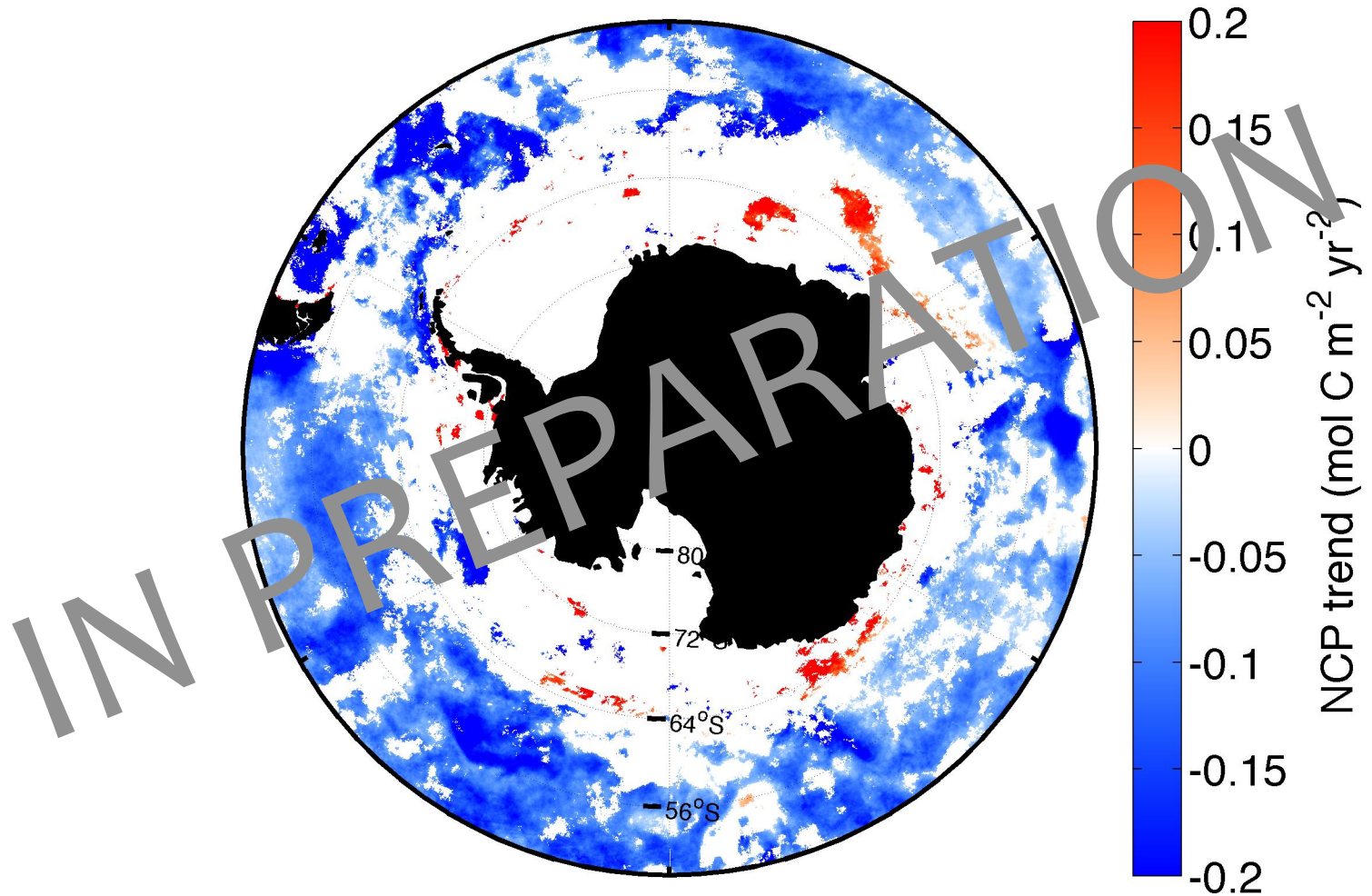
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Primary productivity, 1997-2006



Net community production trend

2003 - 2011



Munro et al. (in prep.)

Conclusions

Known knowns:

- Southern Ocean is a sink for atmospheric CO₂
- Models indicate high variability and significant trends in sea-air CO₂ flux from the Southern Ocean
- Models indicate that wind drives variability and trends in CO₂ flux, via changes in circulation and surface DIC

Known unknowns:

- Is the model-predicted CO₂ flux trend real?
- Has meridional overturning increased?
- Has biological production changed?

The End!