Recent changes in the Southern Ocean biogeochemistry

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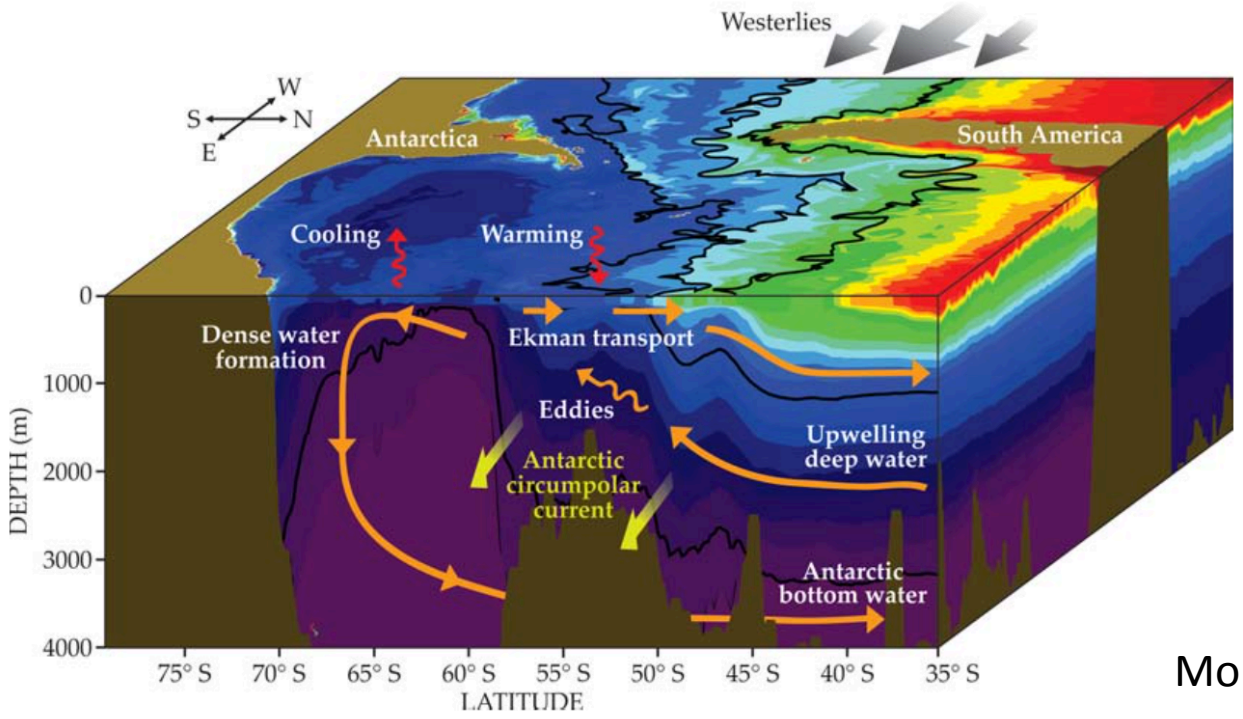
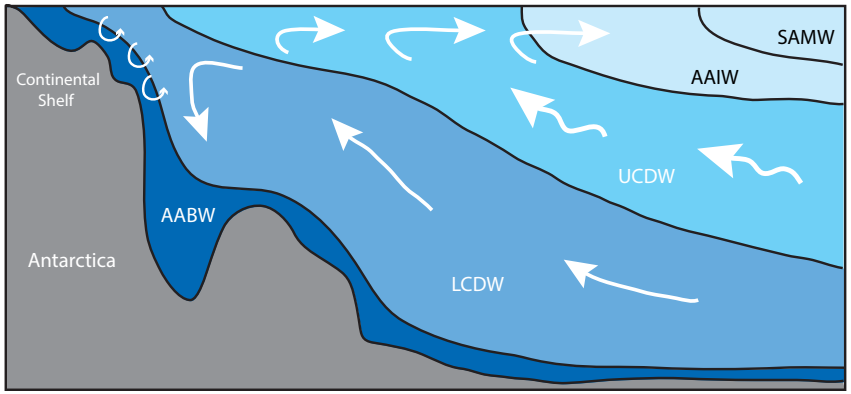
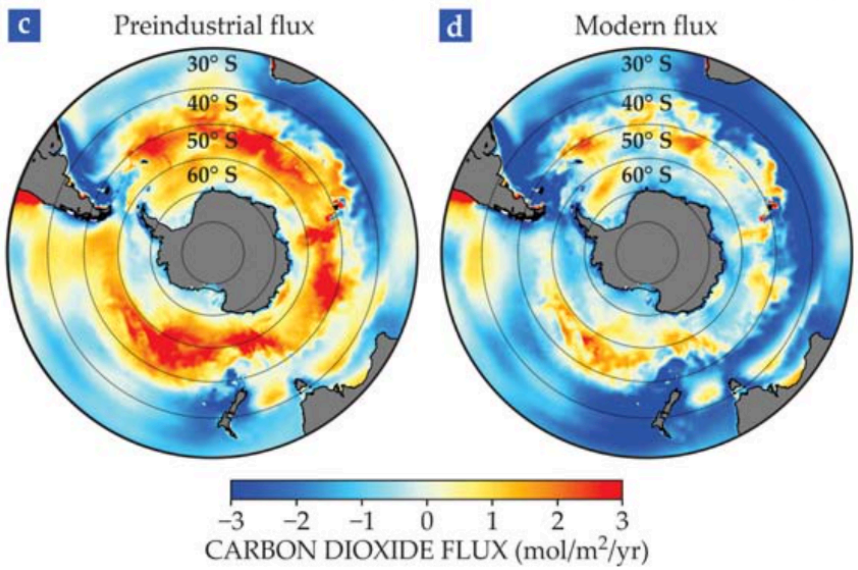


Morrison et al (2015)

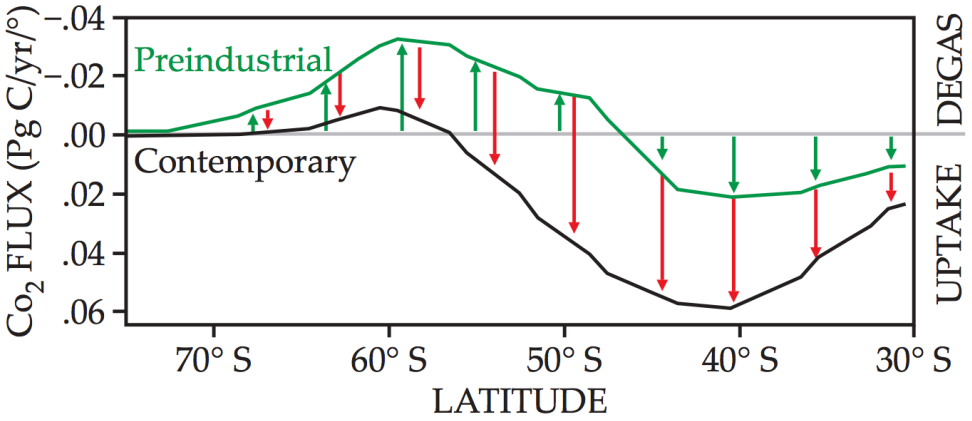
Mean state: upwelling and carbon flux



GFDL CM2.6; Morrison et al., 2015



The Southern Ocean is outgassing natural (preindustrial) carbon and absorbing anthropogenic carbon. They are about the same magnitude poleward of 60°S.



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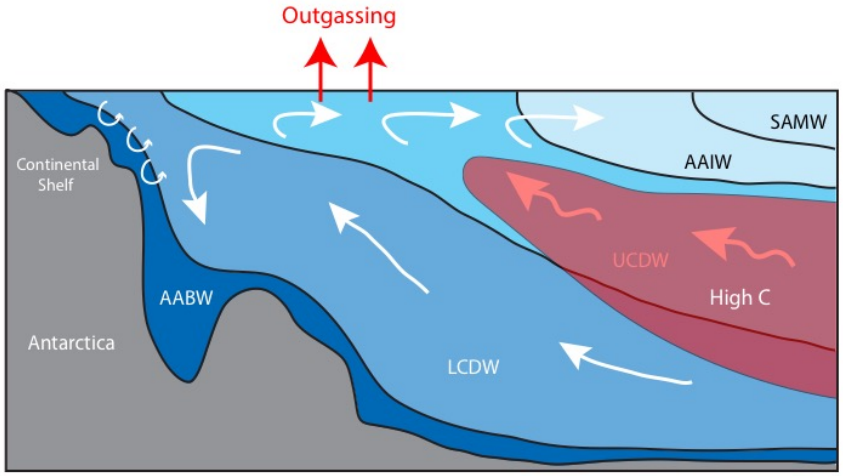

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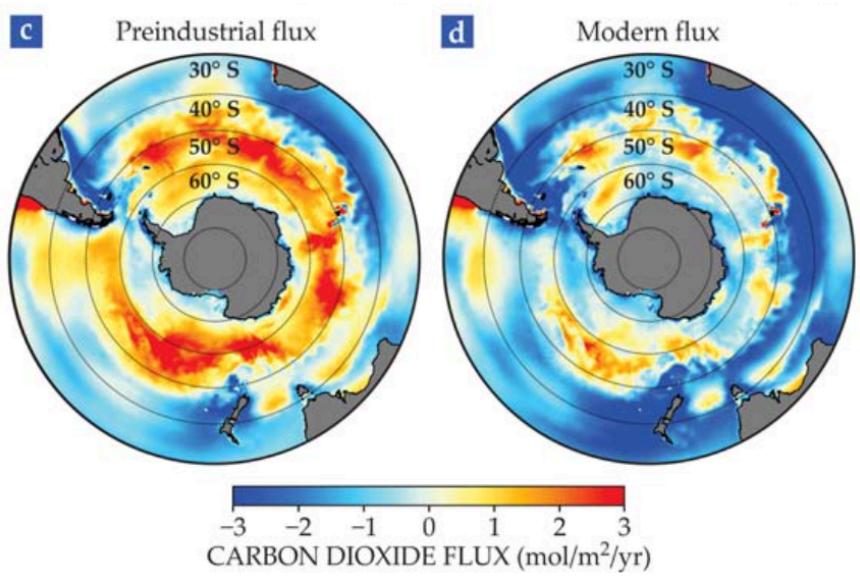

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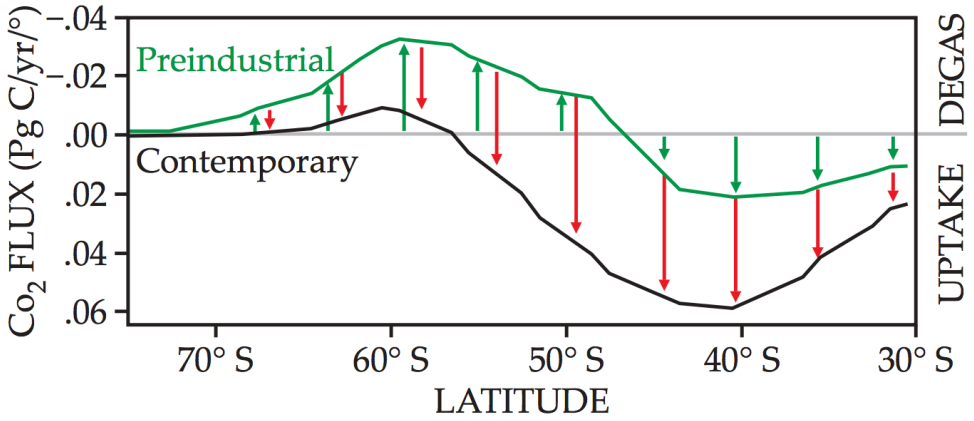

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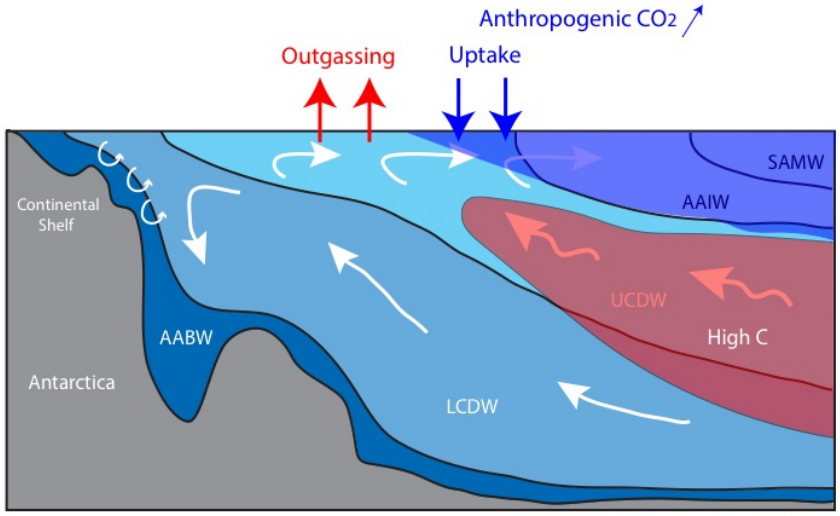

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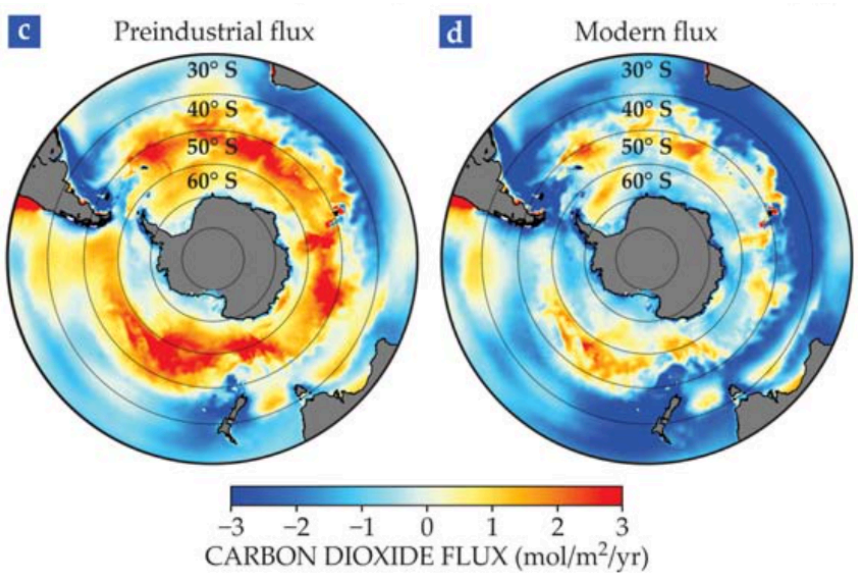

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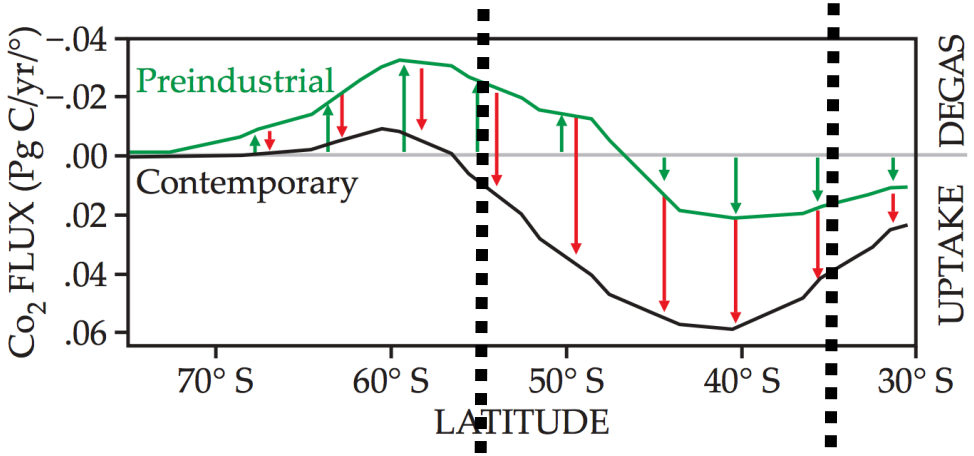
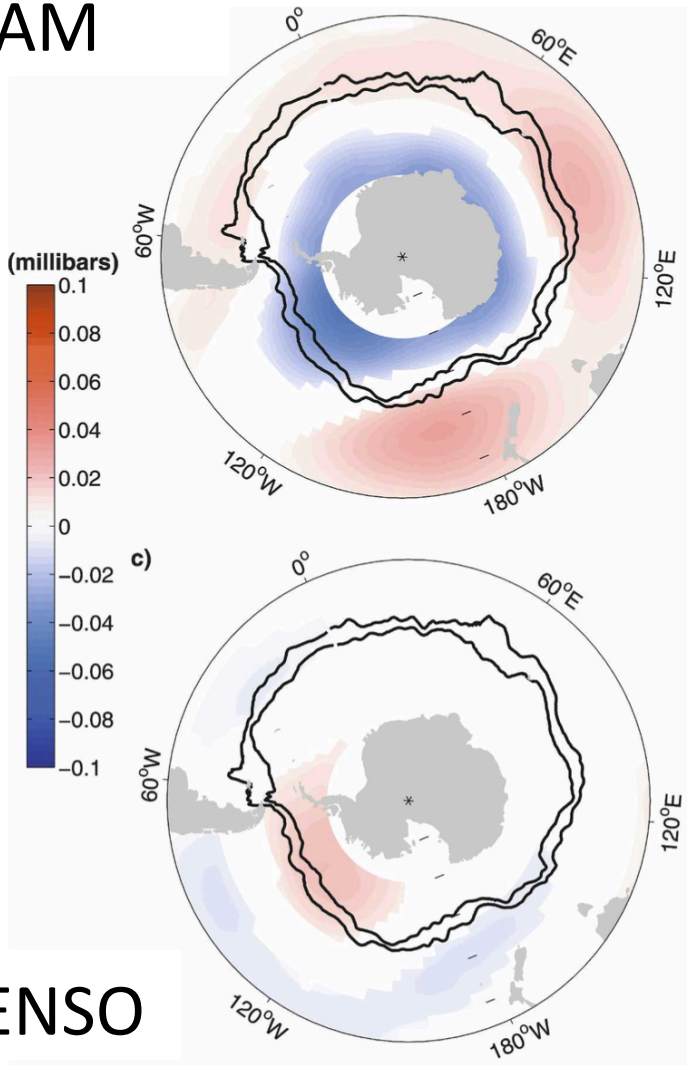


Variability: forcing mechanisms

SAM

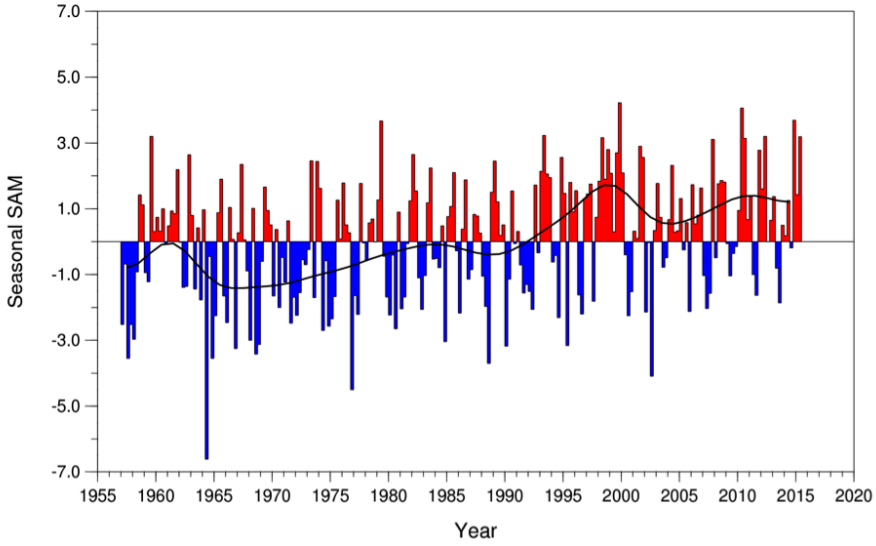


ENSO

Sallee et al., 2008

Positive trend in SAM = **intensified, poleward-shifted zonal wind**

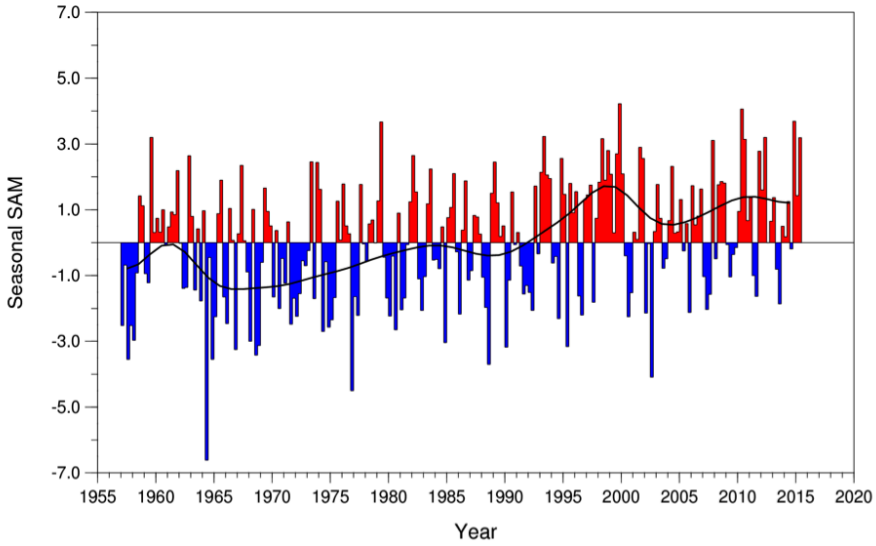
SAM index



Marshall et al., 2016

Changes: upwelling and carbon flux

SAM index



Positive trend in SAM = **intensified, poleward-shifted zonal wind**

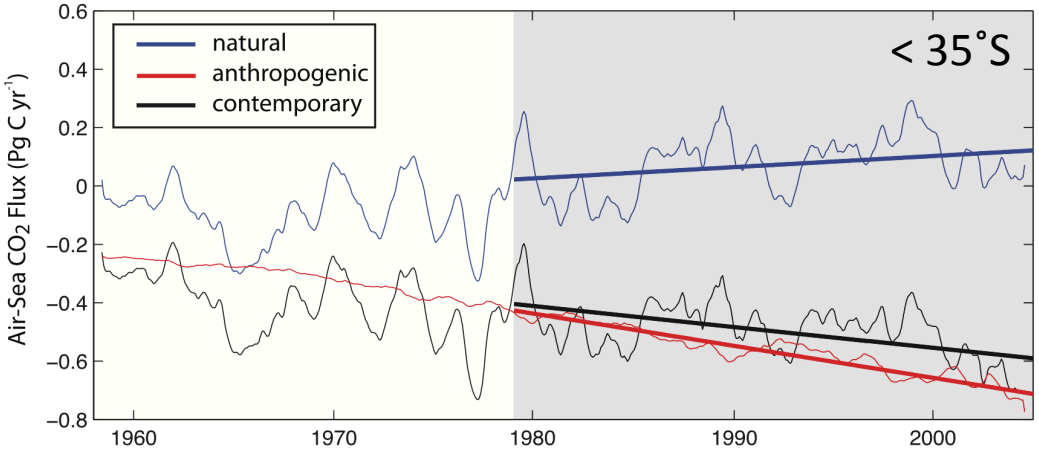
Predict:

→ **Stronger natural C outgassing**

→ **Stronger anthro C uptake**

Less uptake

CCSM/POP hindcast; Lovenduski et al., 2008



+ natural

+ net C uptake

++ anthropogenic

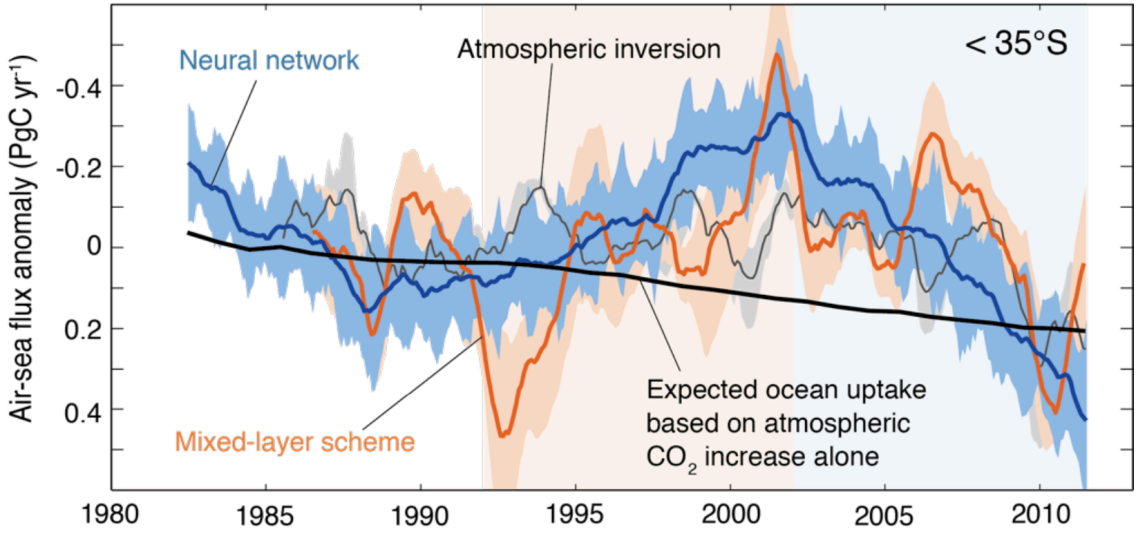
More uptake

Observed changes in sea-air CO_2 flux

$$F_{CO2} = G(u_{10})\, K_H(SST)\, (pCO_{2,ocn} - pCO_{2,atm})$$

- Fay and McKinley (2013) found relatively constant CO_2 uptake during 1980 to early 2000s and then enhanced uptake following mid-2000s (due to cooler SST → higher K_H)

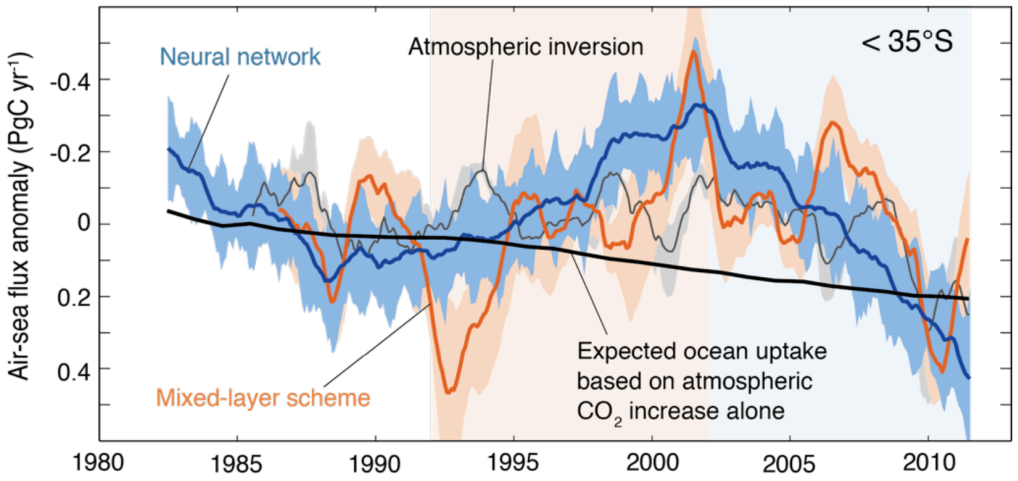
Landschützer et al., 2015



Less uptake

More uptake

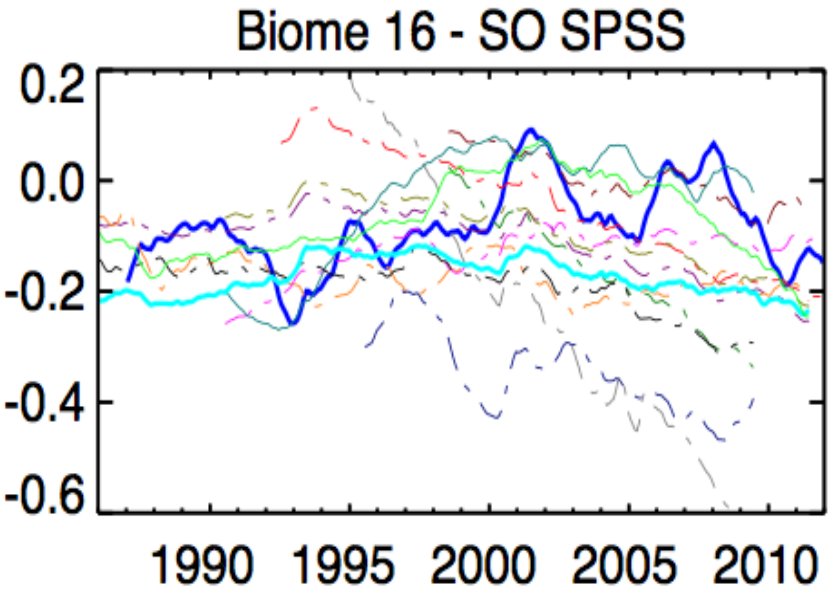
Post-2000s intensification of C uptake?



Less uptake

Landschützer et al., 2015

More uptake

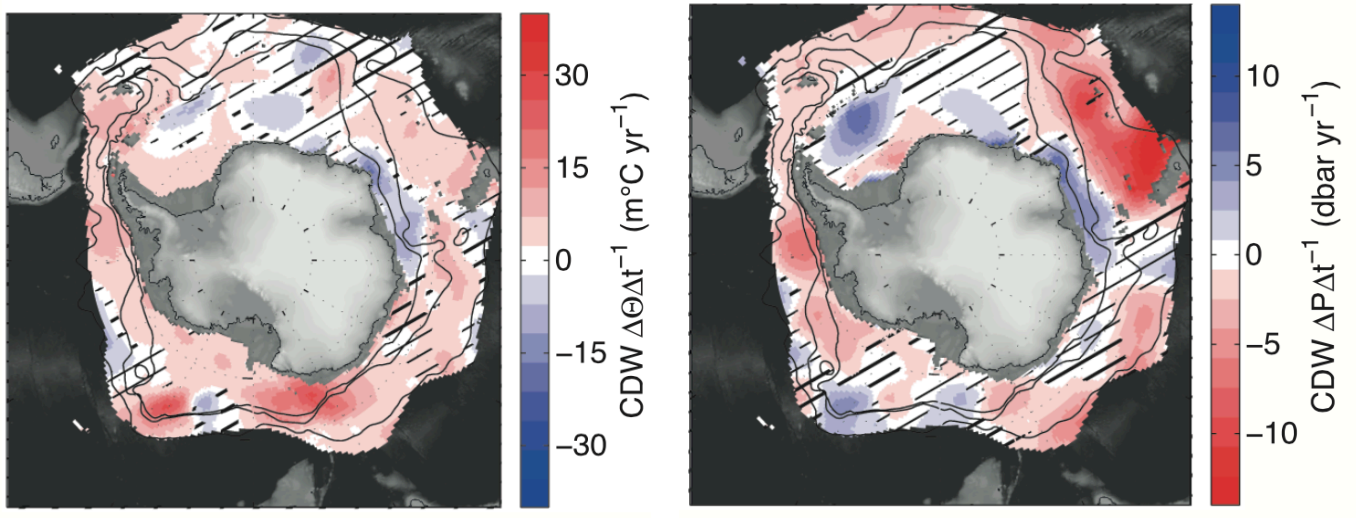


- Rödenbeck et al., 2015 **SOCOM** (surface ocean pCO_2 mapping intercomparison project)
- Data mapping approaches can make a large differences!

Subsurface changes: CDW

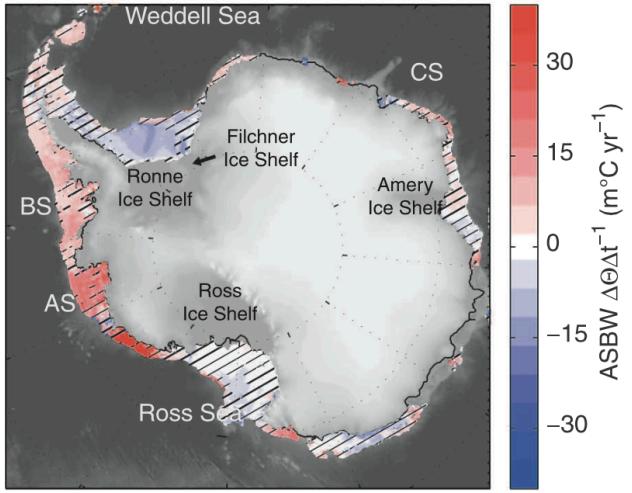
- Gille 2002, 2008; Schmidtko et al., 2014

Trend at CDW core



Core of CDW = Tmax layer

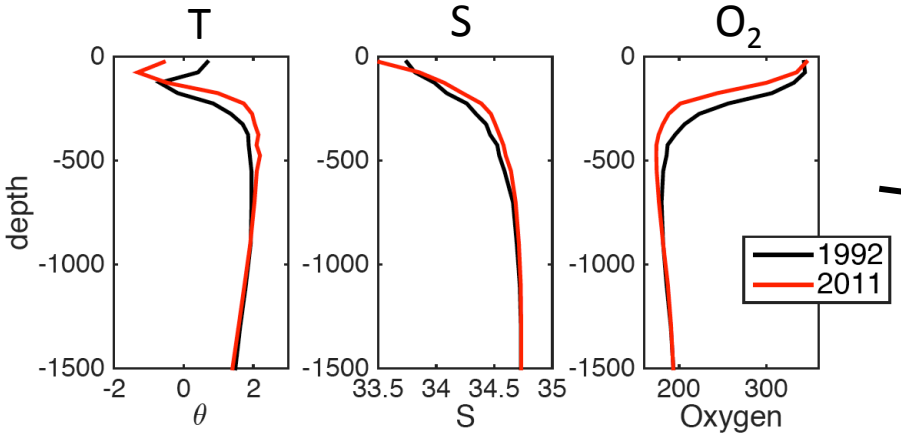
Trend at shelf bottom

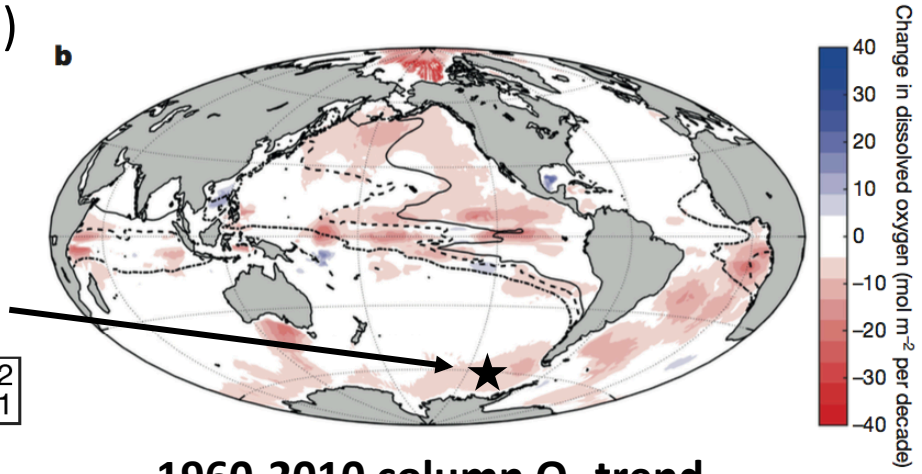


- Since 1970s CDW is generally warming up and shoaling
- Trend is not zonally uniform
- Shelf warming promotes basal melting in the AS/BS sector

Deoxygenation

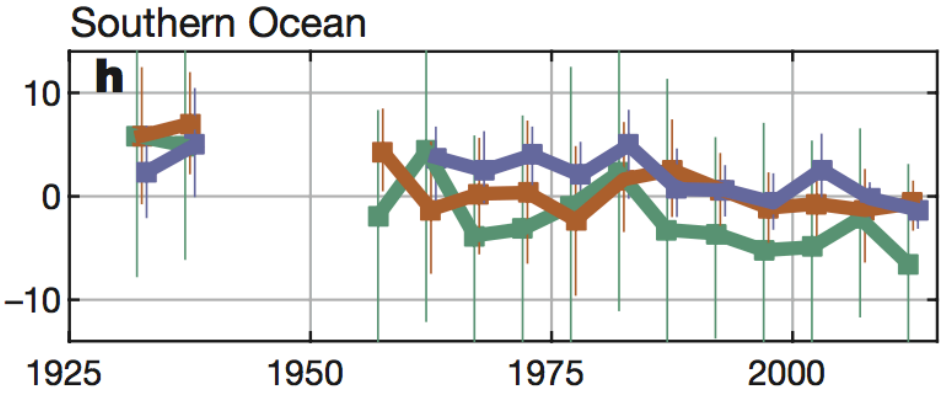
- Large scale obs analysis (Schmidtko et al., 2017; Ito et al., 2017)
- Vertical profiles (S4P, 1992 & 2011)





1960-2010 column O_2 trend

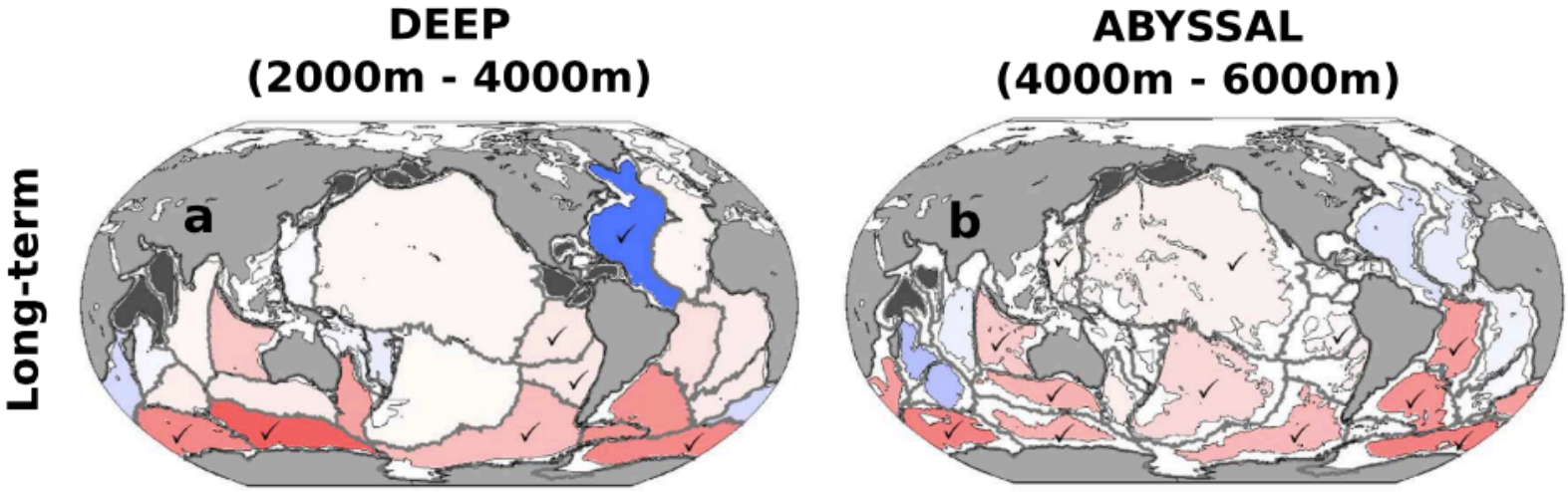
CDW is getting shallower, warmer and less oxygenated



Green (300m); Red (1000m); Blue (3000m)

Subsurface changes: Deep Waters

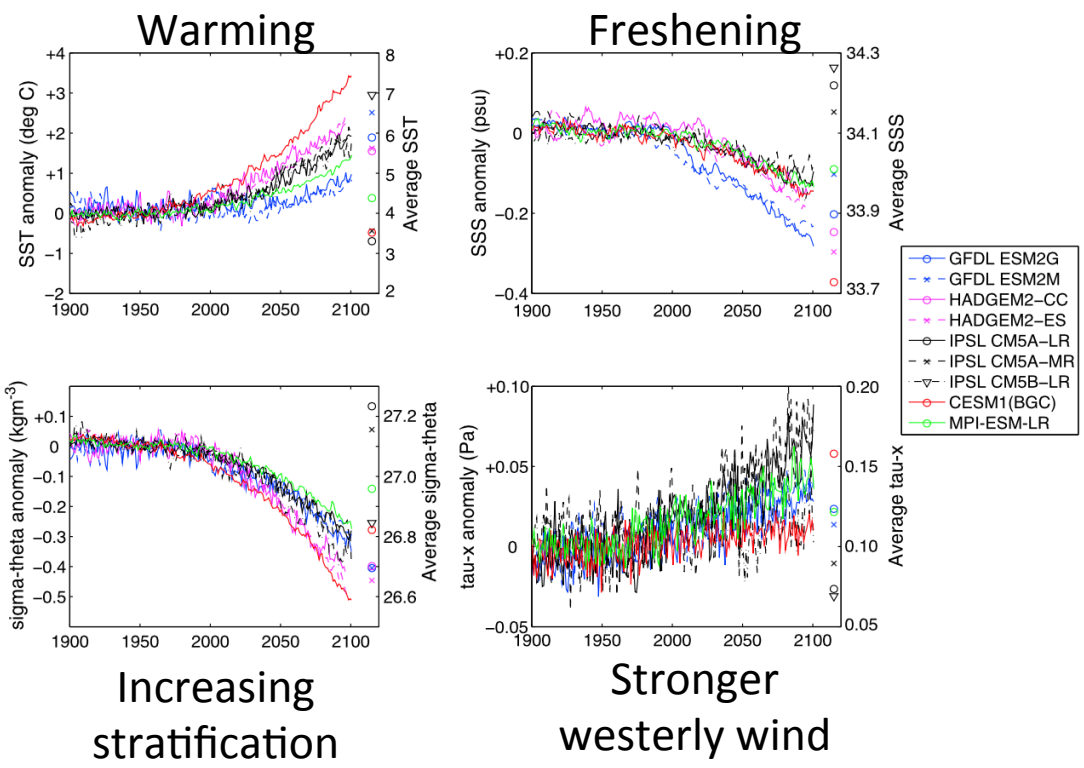
- Purkey and Johnson, 2013; Desbruyeres et al., 2013



- Freshening of AABW and glacial melt (Rignot et al., 2008; Jacobs and Giulivi 2010; Swift and Orsi 2012)
- Weakening of the lower limb MOC (Purkey and Johnson 2012; Kouketsu et al., 2011) → **consistent with deep O_2 loss**

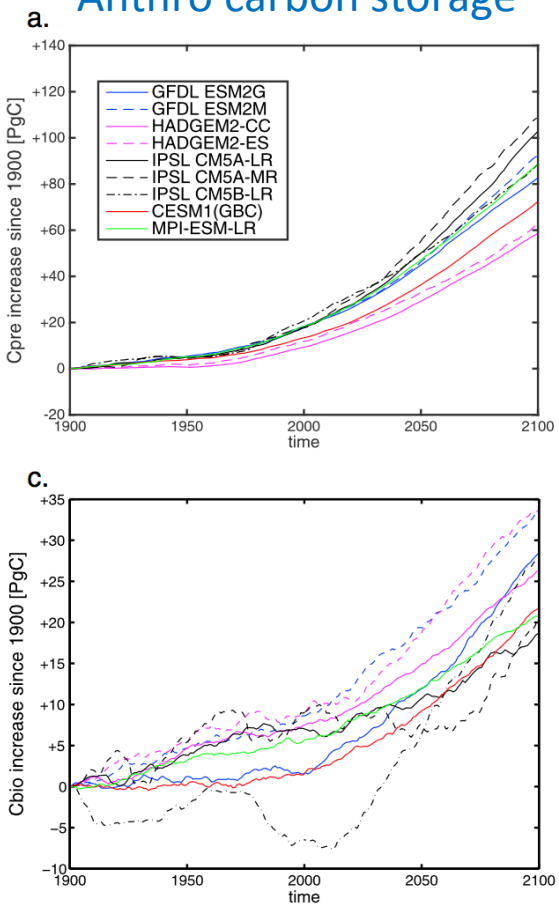
Projected trends in the 21st century

- Ocean Carbon Uptake WG; CMIP5 analysis



Ito, Bracco, Deutsch et al., (2015)

Anthro carbon storage

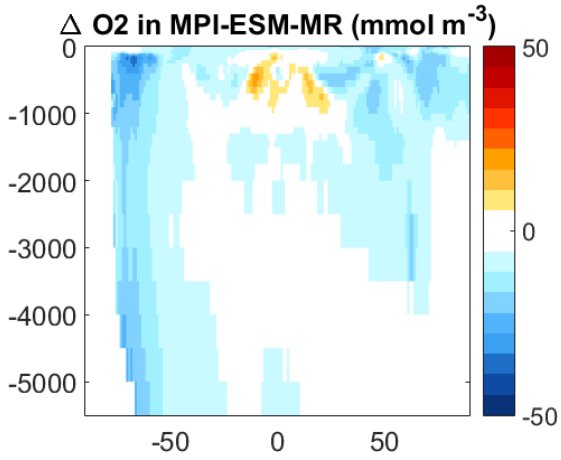


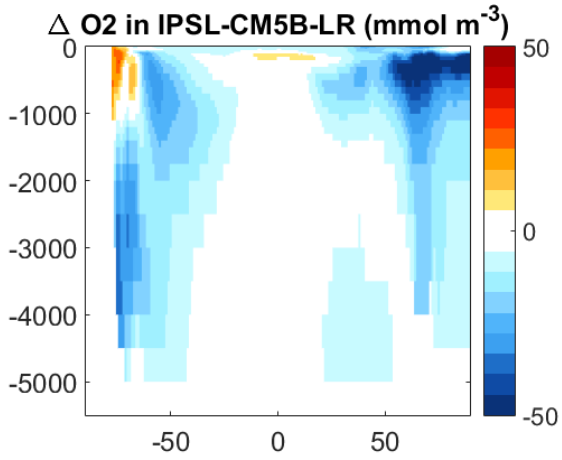
+ Biological carbon storage

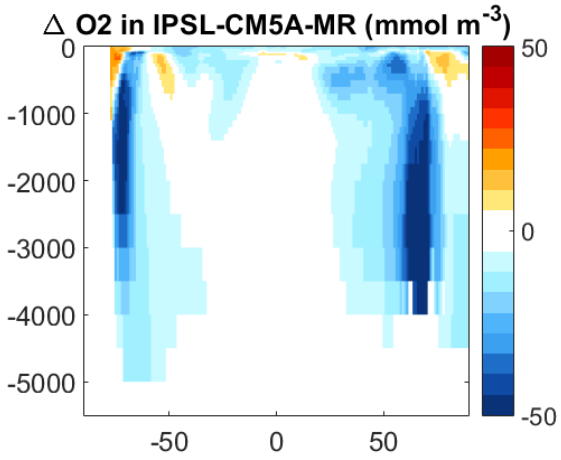
Centennial deep O_2 loss

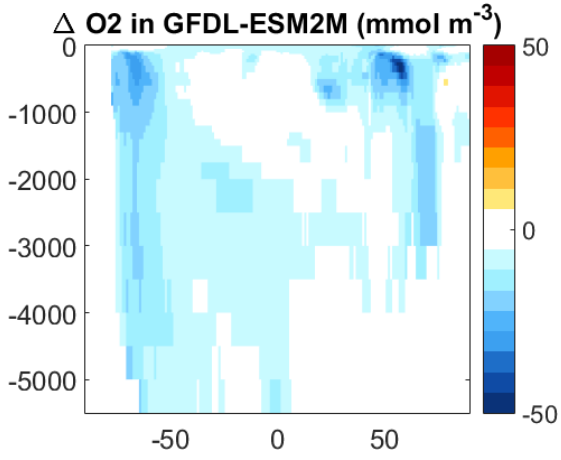
D. Sun

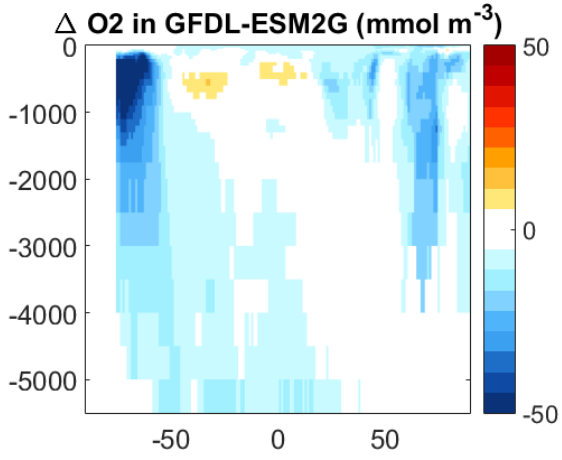
- 21st century changes in zonal mean O_2 (2090s – 2000s)

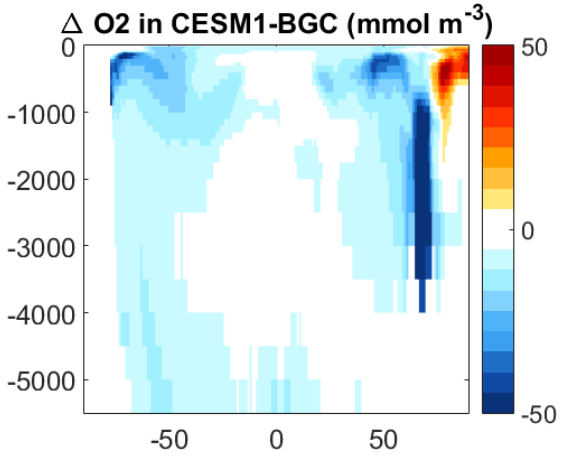






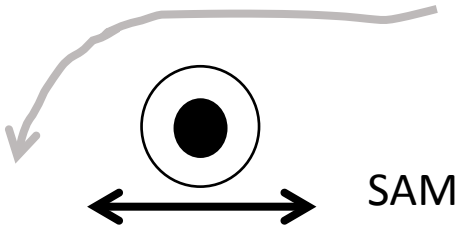




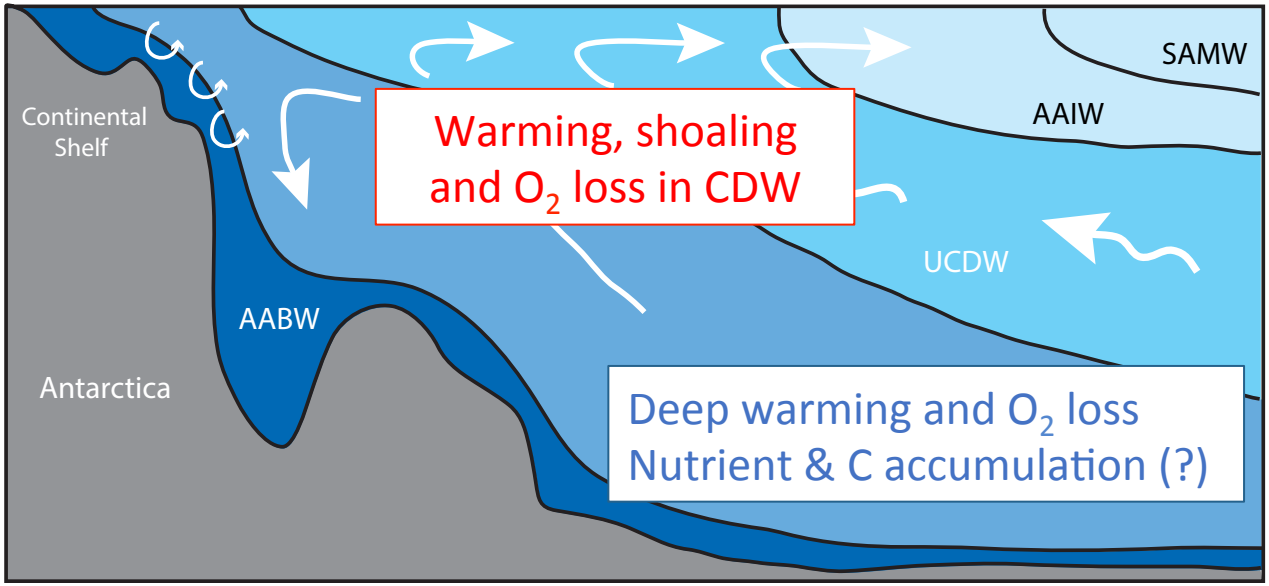


Summary

Post-2000s stronger CO_2 uptake (?)



Relatively flat CO_2 uptake during 1980-1990s (?)



Concluding remarks

- The Southern Ocean CO_2 and other biogeochemical variables exhibit significant (multi-) decadal and IAV and they are not uniform; different mechanisms may be at play at different regions and depths

- Observations, especially in the subsurface, are very sparse and irregular but are improving (e.g. SOCCOM).

- Models have biases and cannot fully reproduce obs, but are crucial for mechanistically linking processes to observables