Annual CO_2 and O_2 dynamics in the Ross Sea, Antarctica

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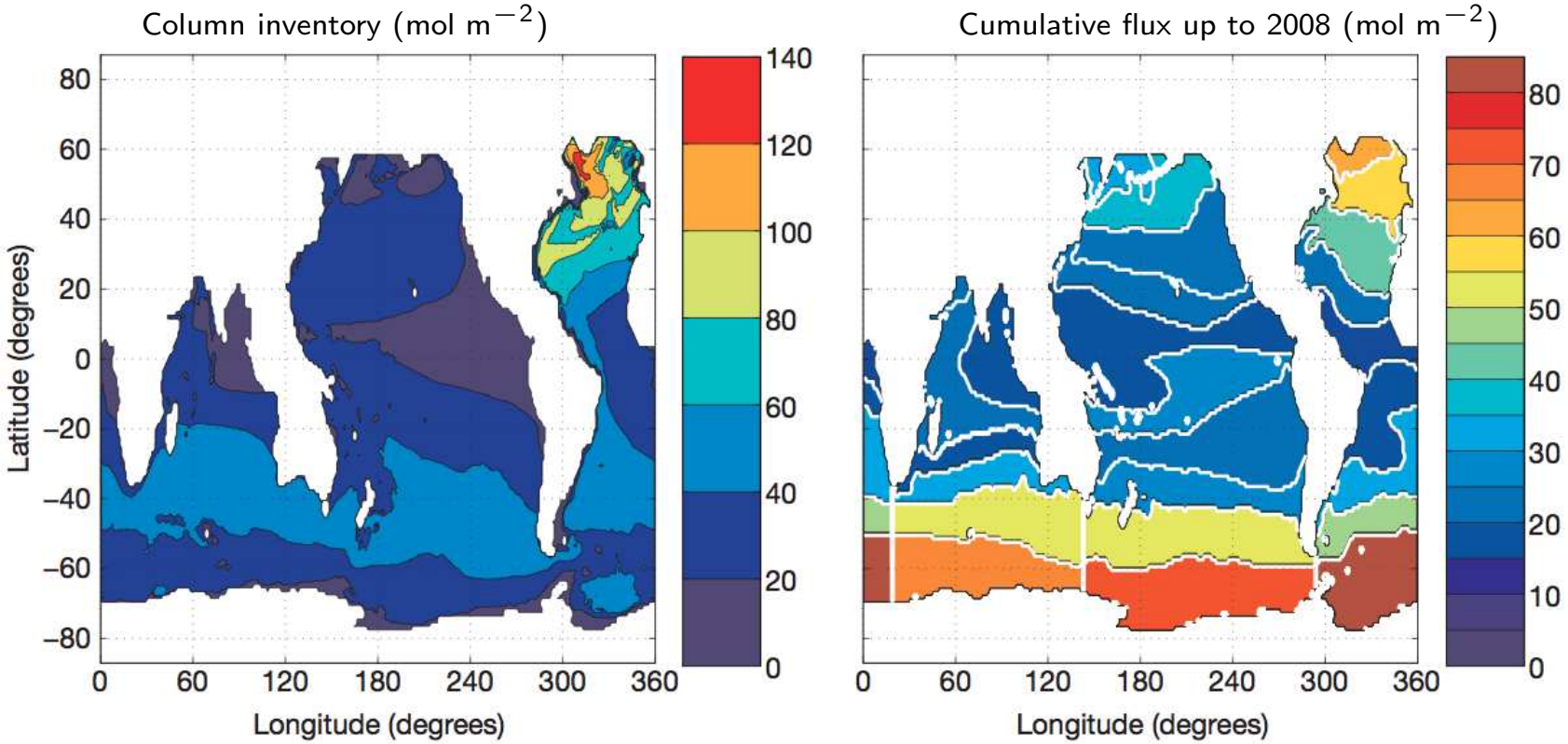
Importance of the Southern Ocean

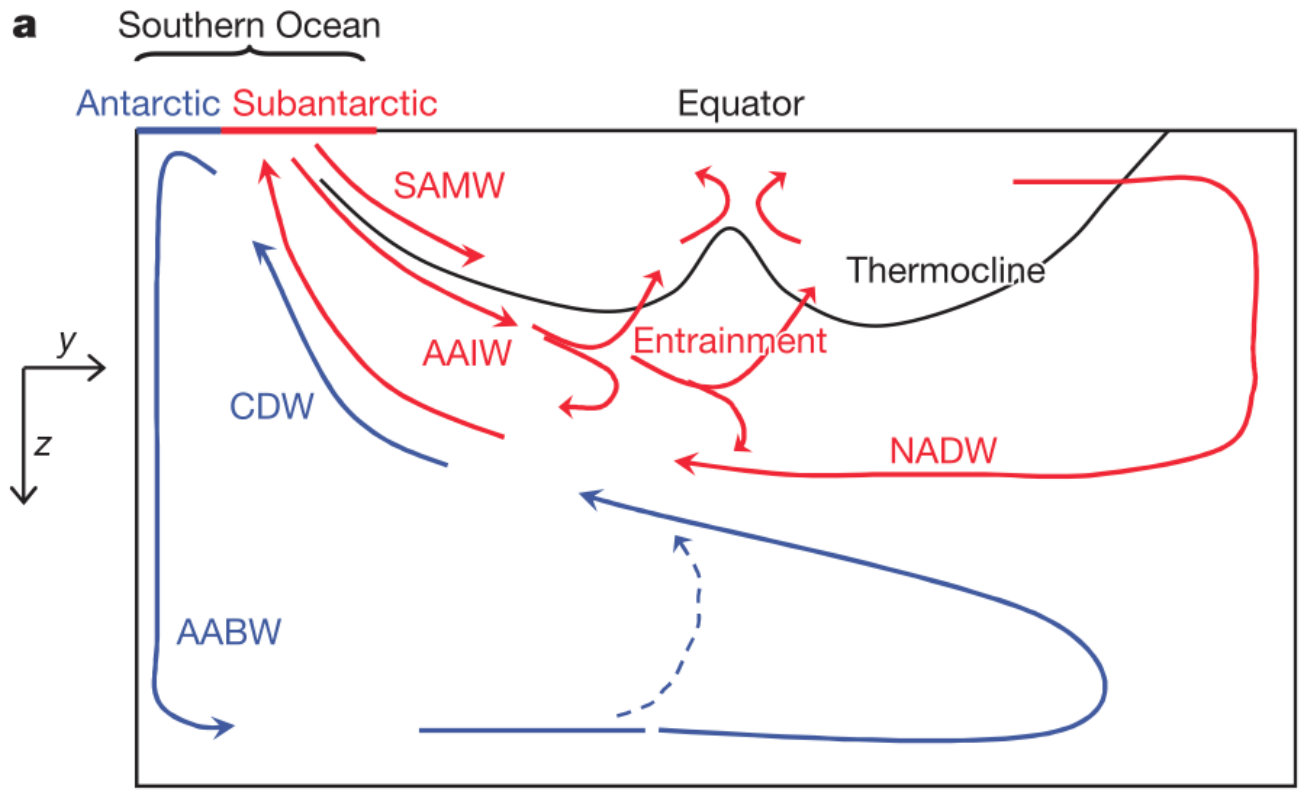
Anthropogenic CO_2



based on tracer time distributions

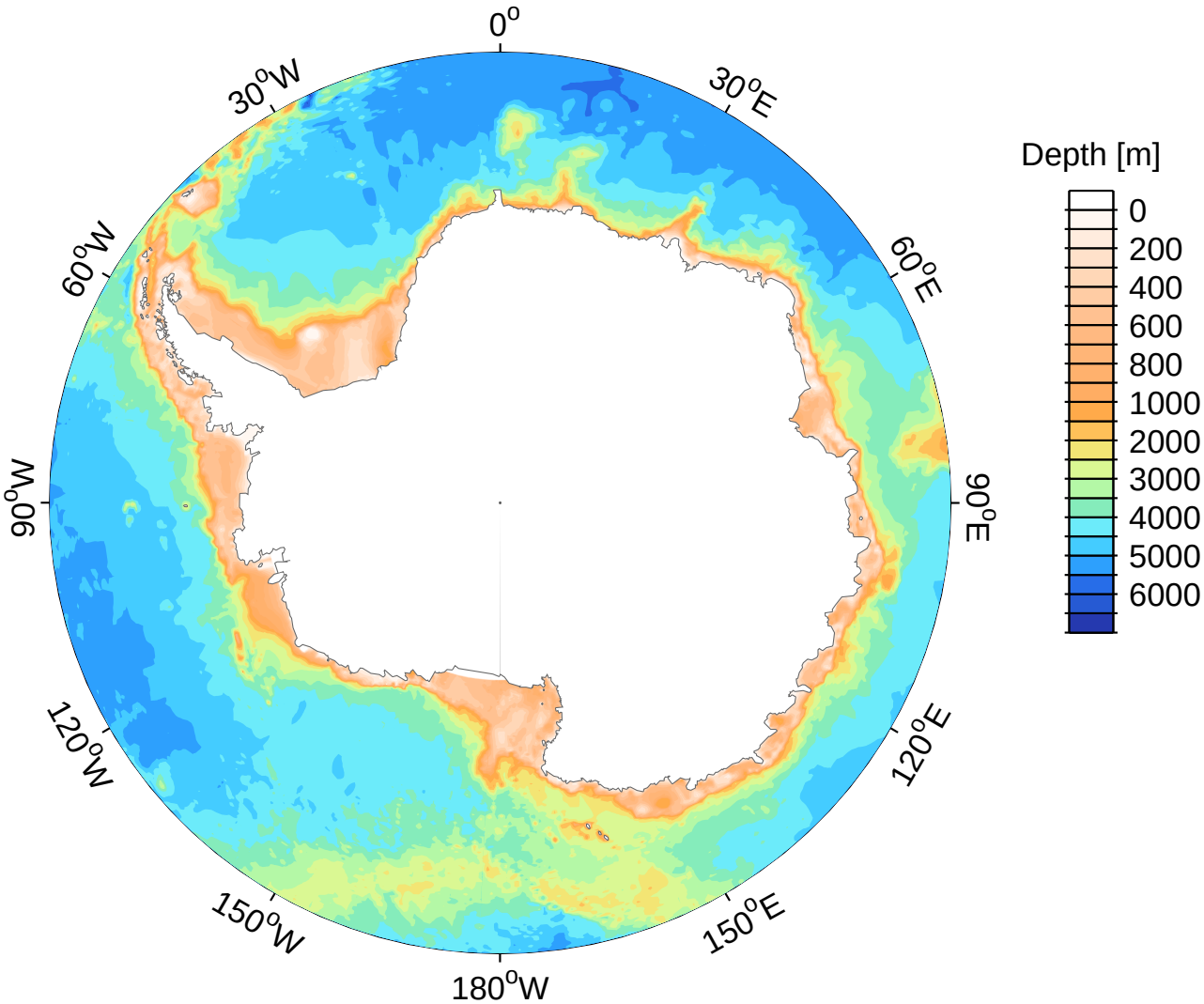
Khatiwala et al. 2009

Southern Ocean

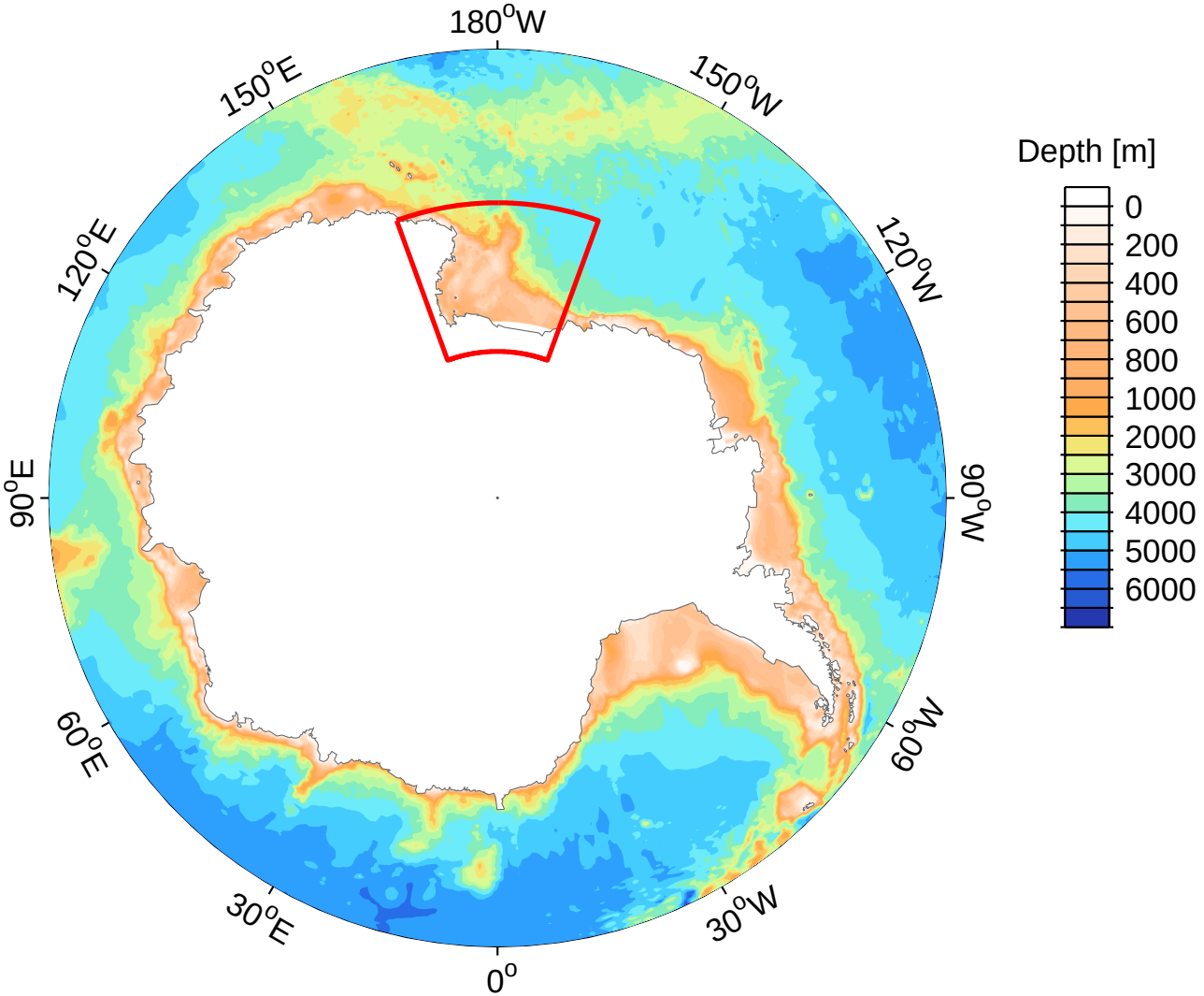


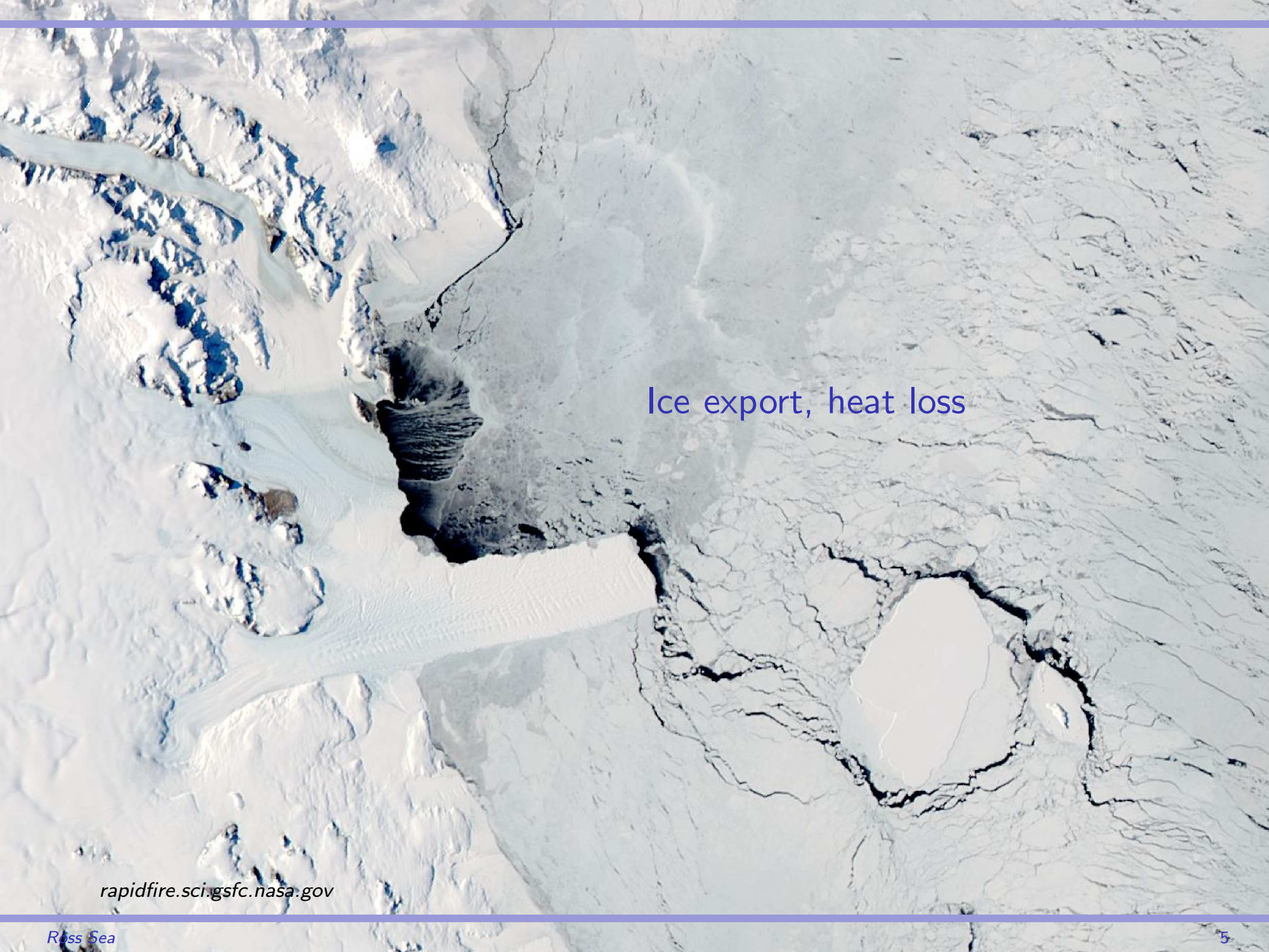
Marinov et al. 2006

Antarctic continental shelves

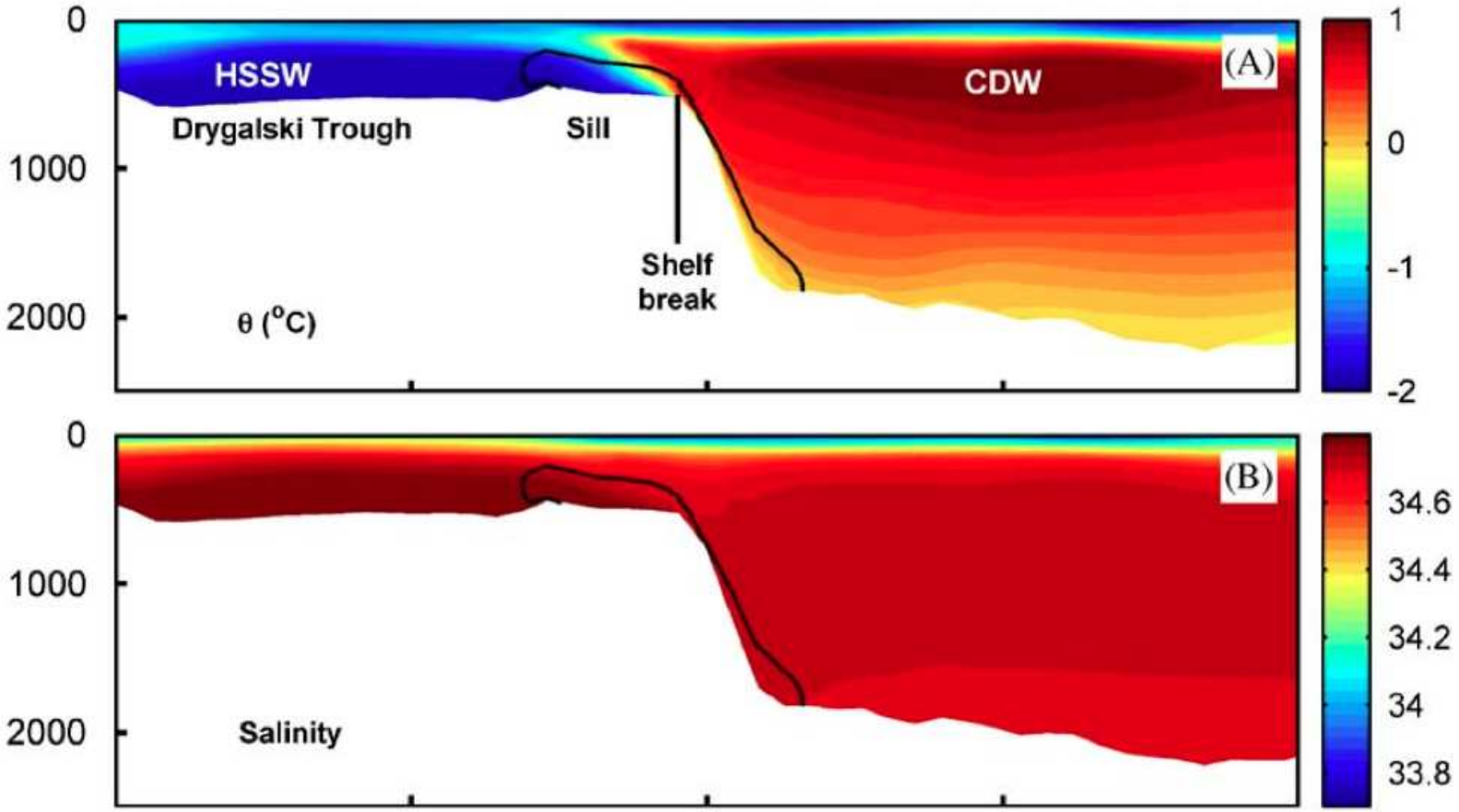


Ross Sea


180°W
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
Depth [m]
0
200
400
600
800
1000
2000
3000
4000
5000
6000

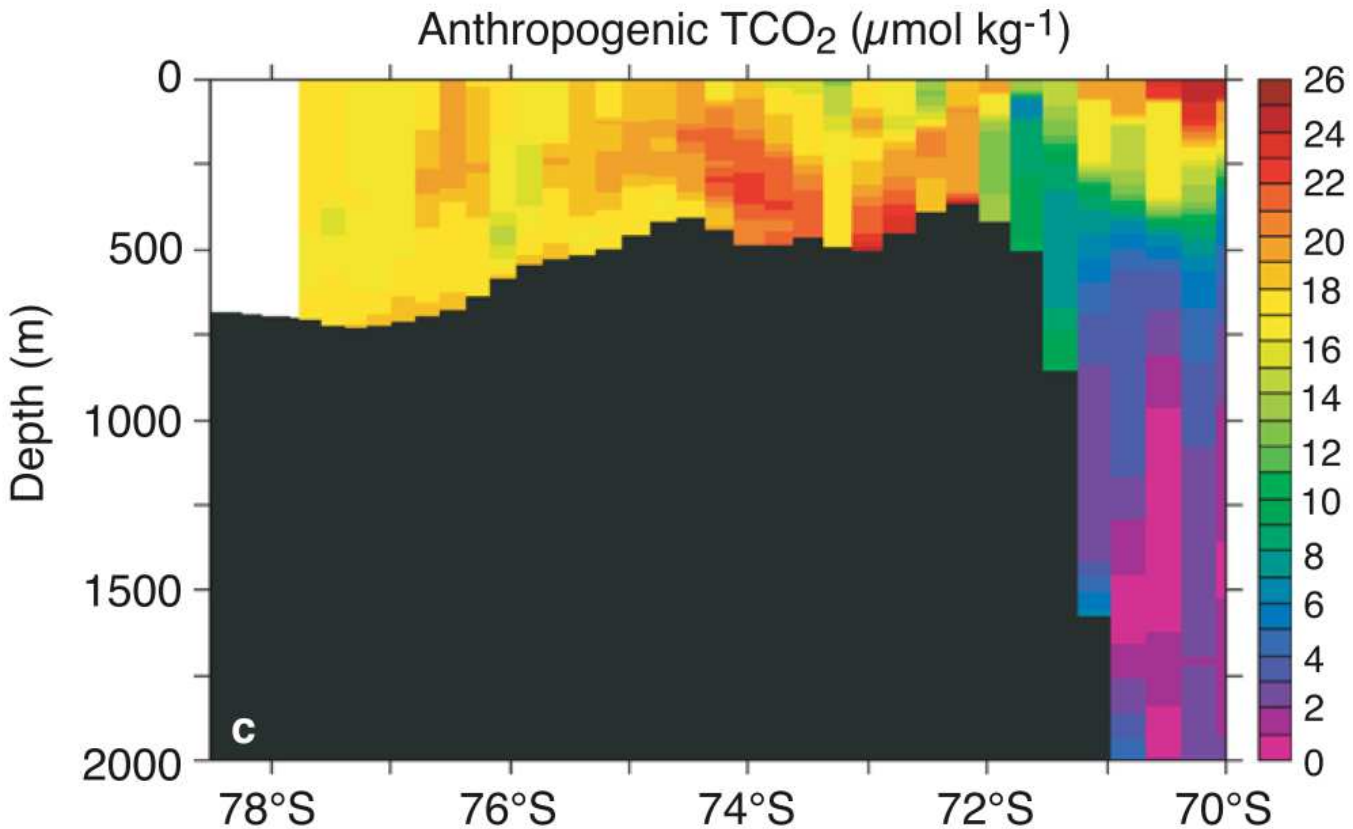

Ice export, heat loss
rapidfire.sci.gsfc.nasa.gov

Deepwater formation



Padman et al. 2009

CO_2 sink



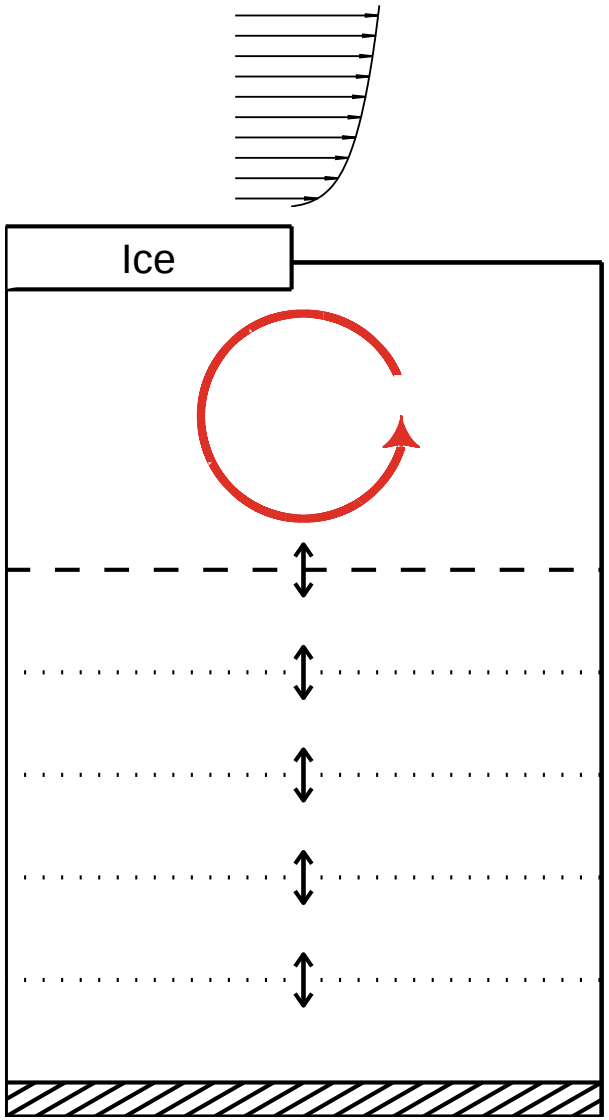
along 171° E

Arrigo et al. 2008

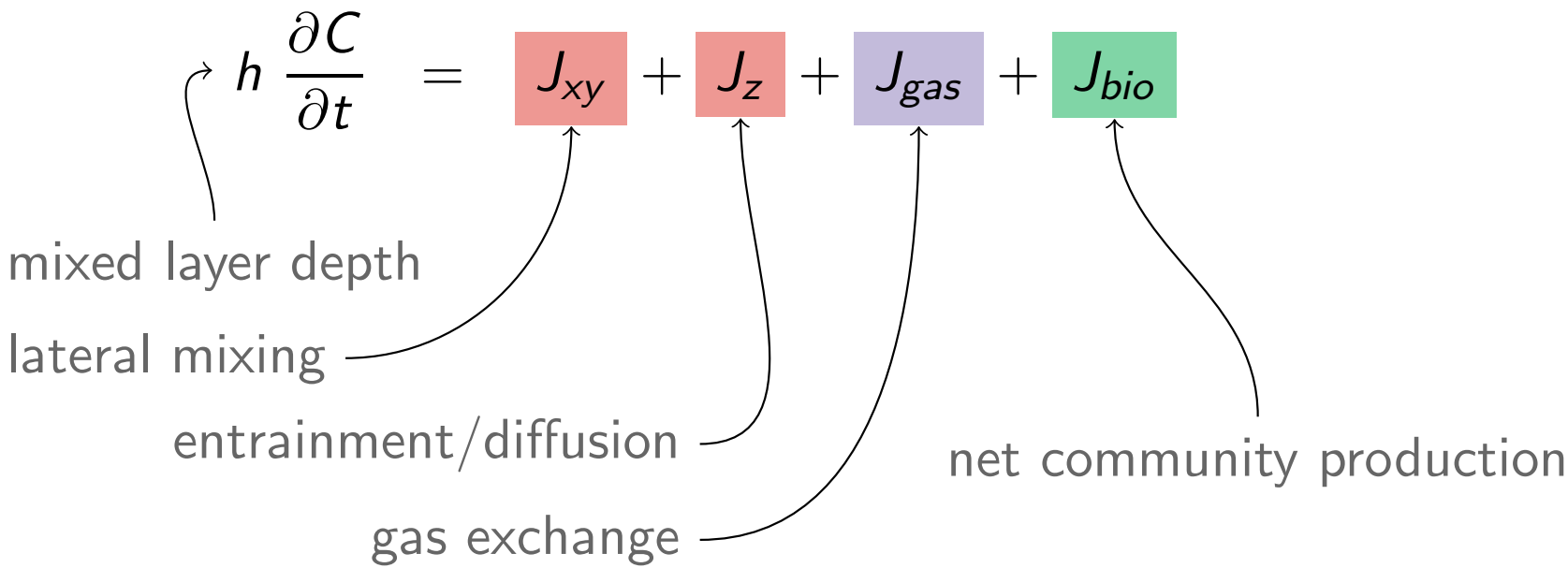
Key questions

1. What are the mechanics of the Ross Sea CO_2 sink?
2. What are the sensitivities of the system?
3. How do key variables scale relatively?

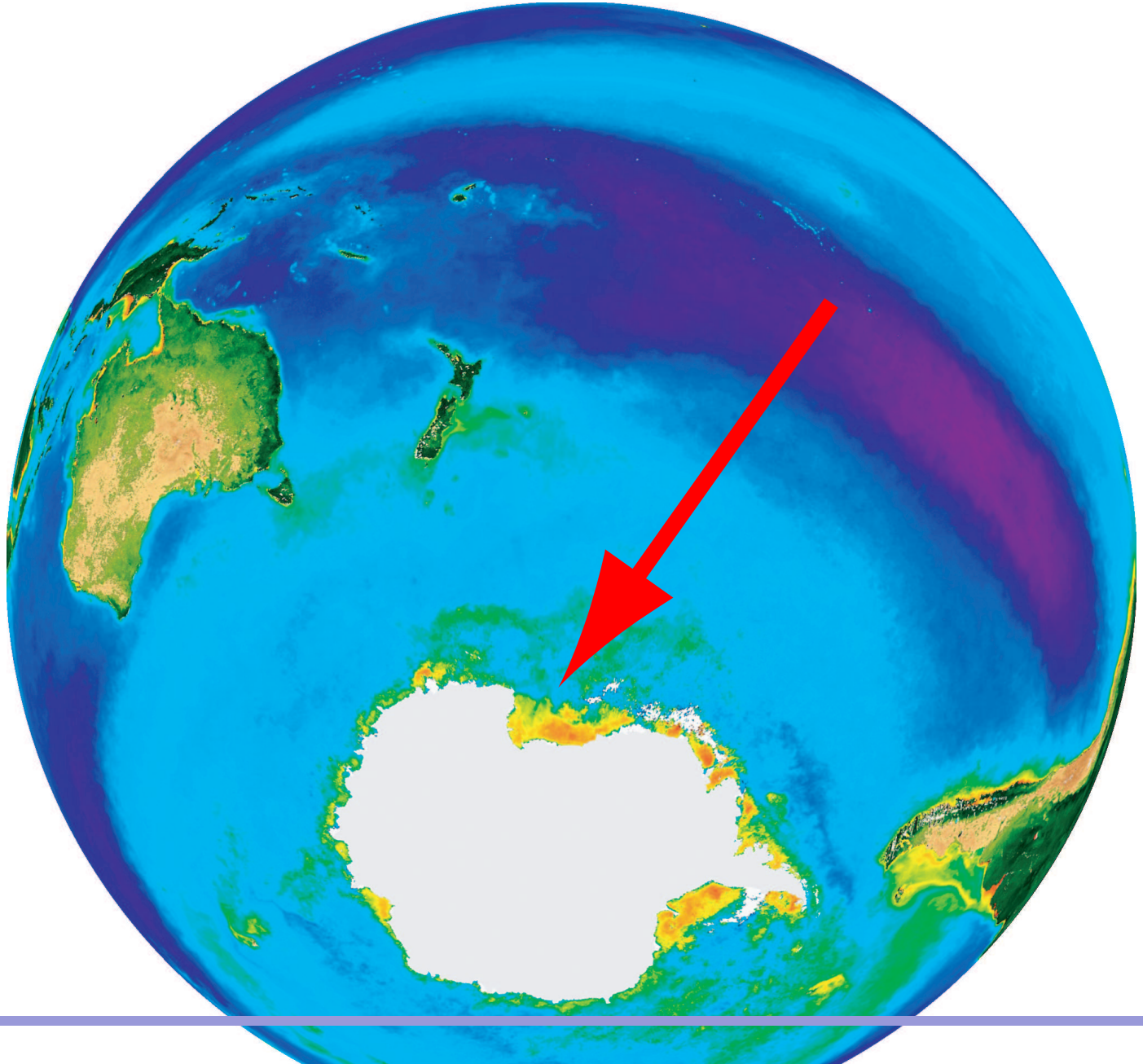
Upper ocean mass balance



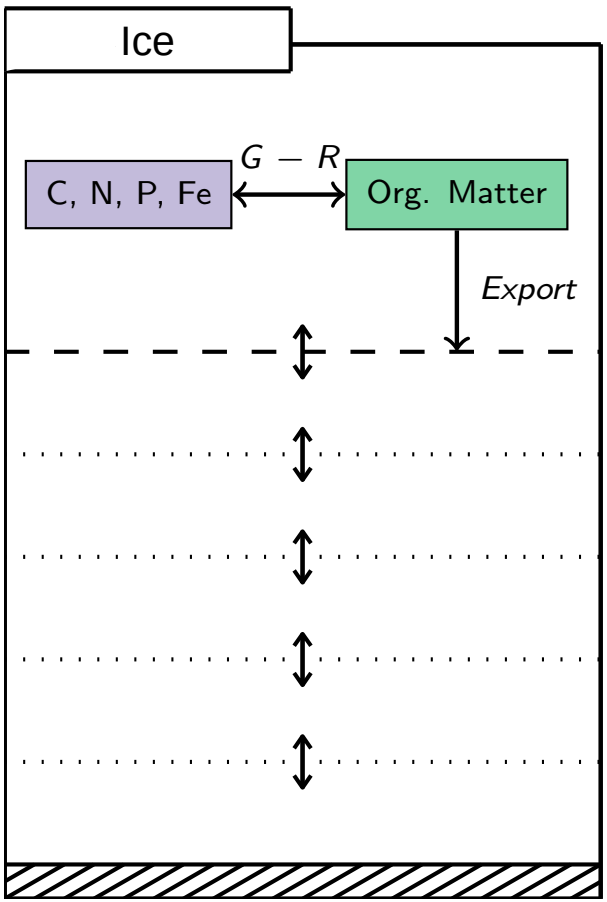
Upper ocean mass balance



Net community production

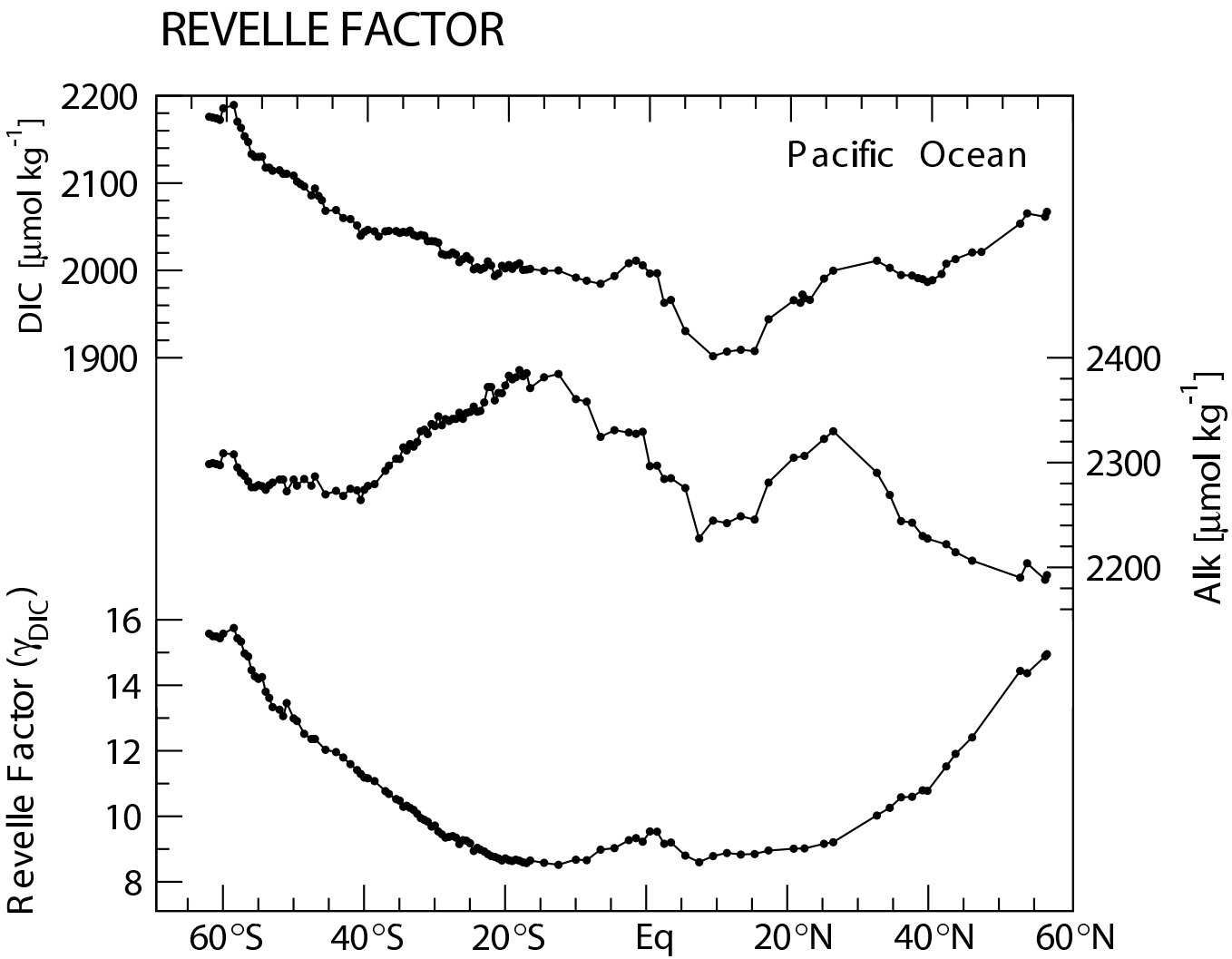


Net community production



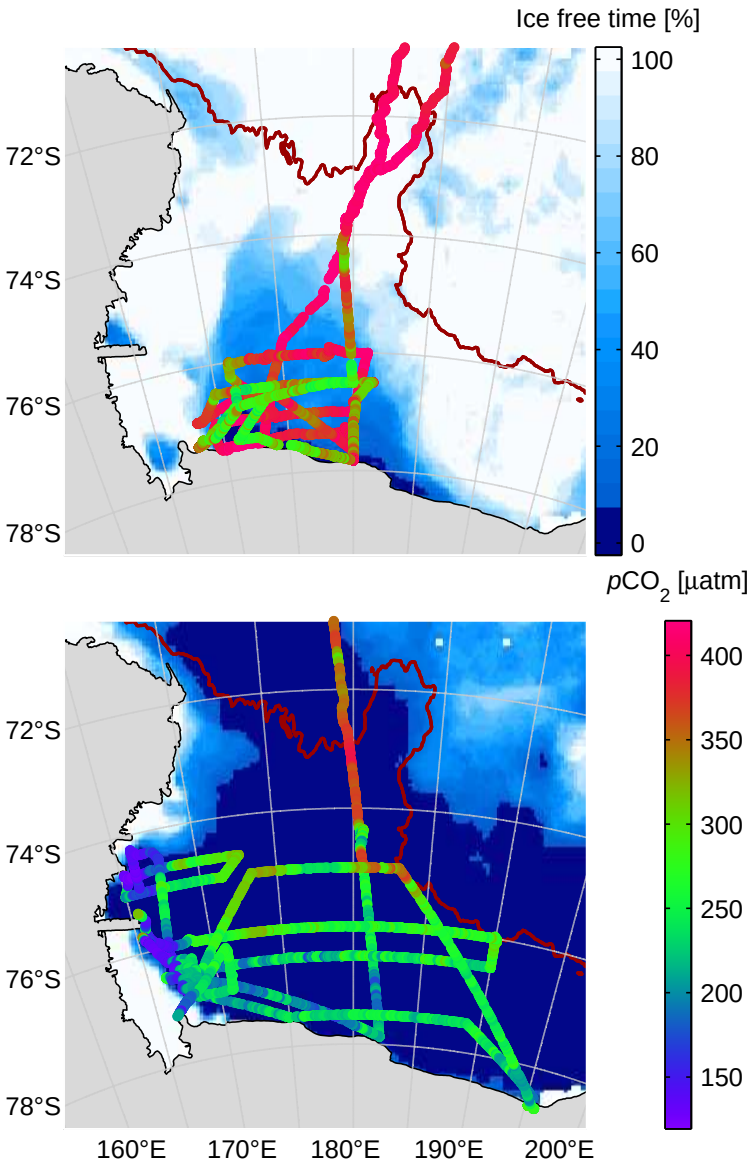
$$h\frac{\partial C}{\partial t} = J_{phy} + J_{gas} + J_{ncp}$$

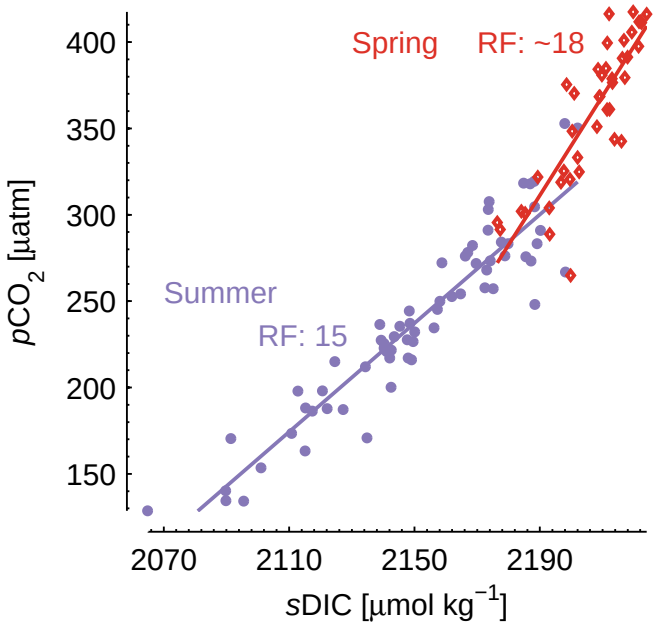
High latitude, weakly buffered



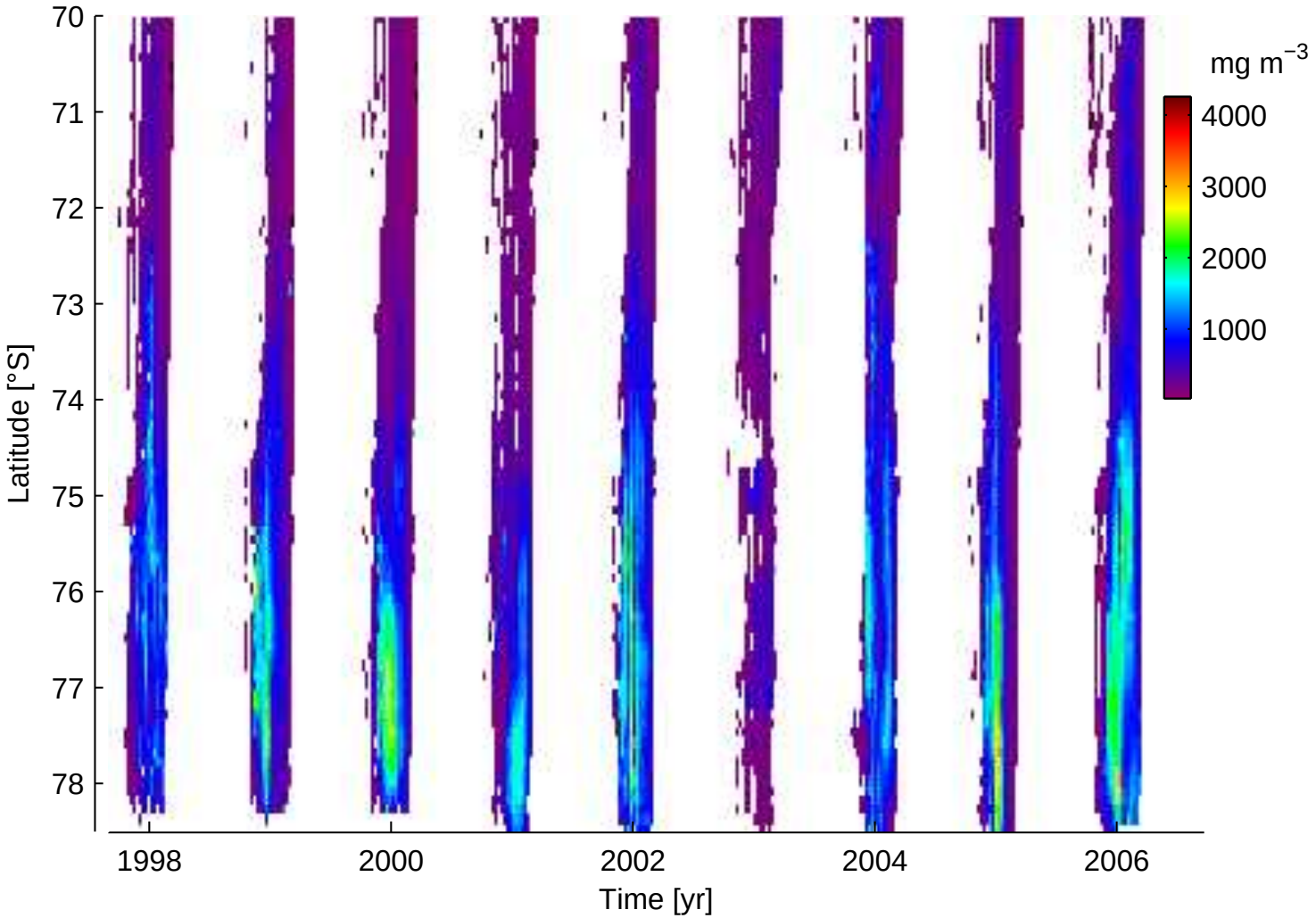
Sarmiento & Gruber 2006

Extreme drawdown



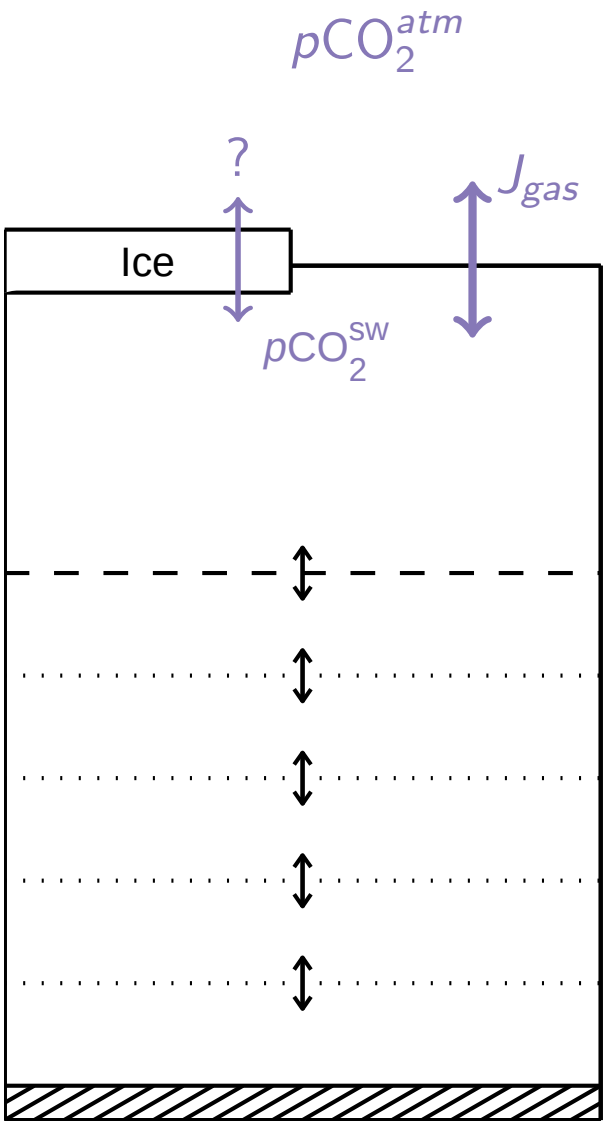


Seasonality



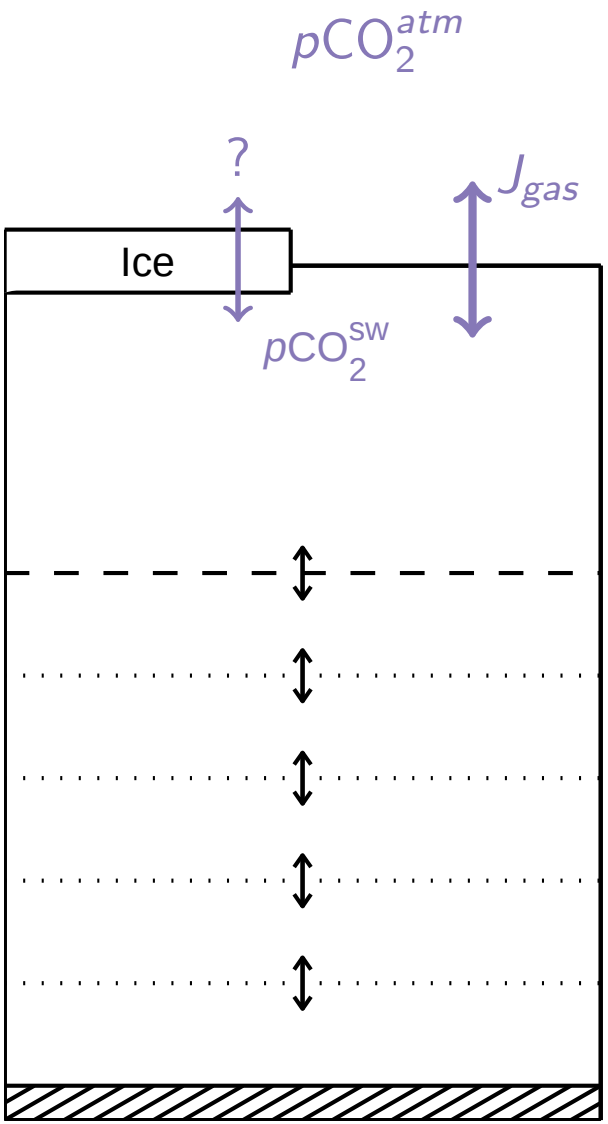
SeaWiFS-derived primary productivity along 180° E, Arrigo algorithm

Gas exchange



$$h\frac{\partial C}{\partial t} = J_{phy} + J_{gas} + J_{ncp}$$

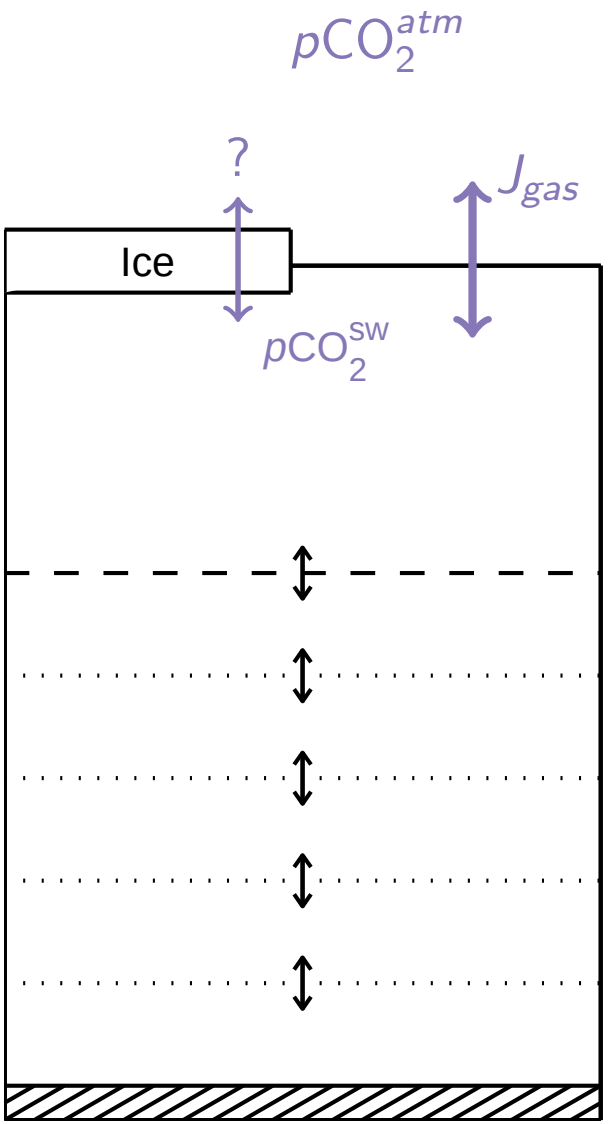
Gas exchange



$$J_{gas,O_2} = k^{O_2}\left(O_{2,sat} - O_2^{sw}\right)$$

$$J_{gas,CO_2} = k^{CO_2}\gamma\left(pCO_2^{atm} - pCO_2^{sw}\right)$$

Gas exchange

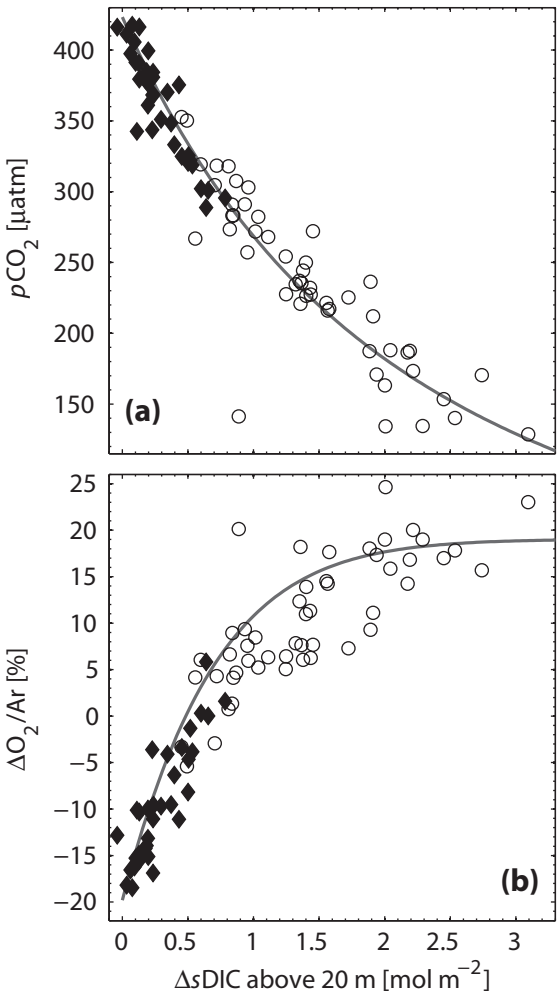


$$J_{gas,O_2} = (1-A)\, k^{O_2} \Delta O_2$$

$$J_{gas,CO_2} = (1-A)\, k^{CO_2} \gamma \Delta pCO_2$$

where A is the fractional ice coverage.

Differing O_2 and CO_2 dynamics



Lines show 1-box model simulation with constant NCP (39.5 mmol C m^{-2} d^{-1}) and constant wind (4.2 m s^{-1}).

- Air-sea exchange is more sluggish for CO_2 than for O_2.

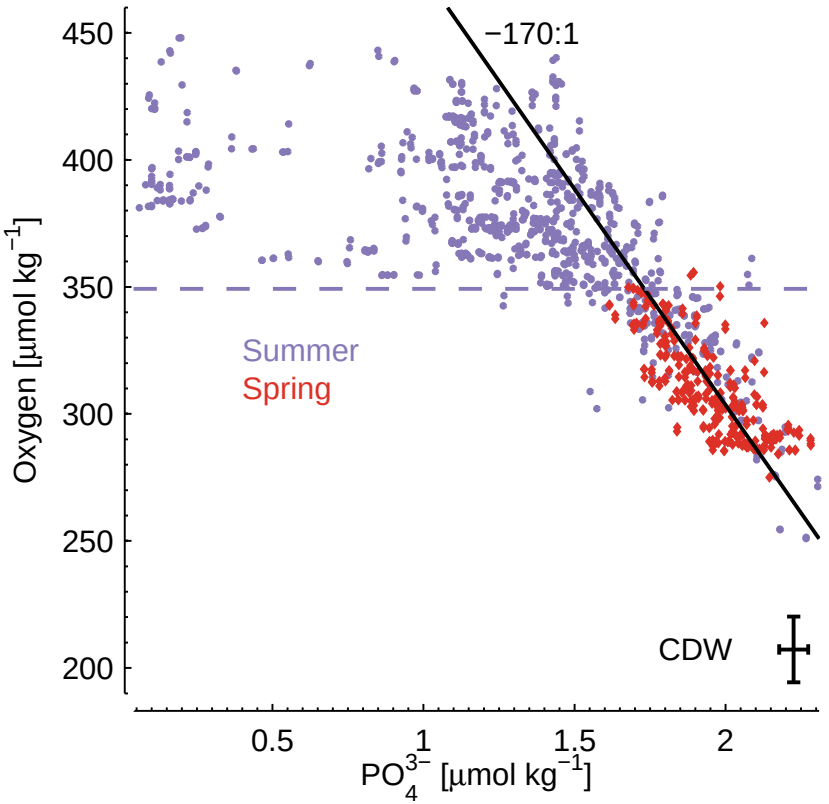
  pCO_2 continues to decline after O_2 concentrations have stabilized.

$$\Delta O_2/Ar = \frac{(O_2/Ar)_{sw}}{(O_2/Ar)_{sat}}$$

$\Rightarrow$ biological oxygen saturation (bubble and state change components removed)

Excess O_2?

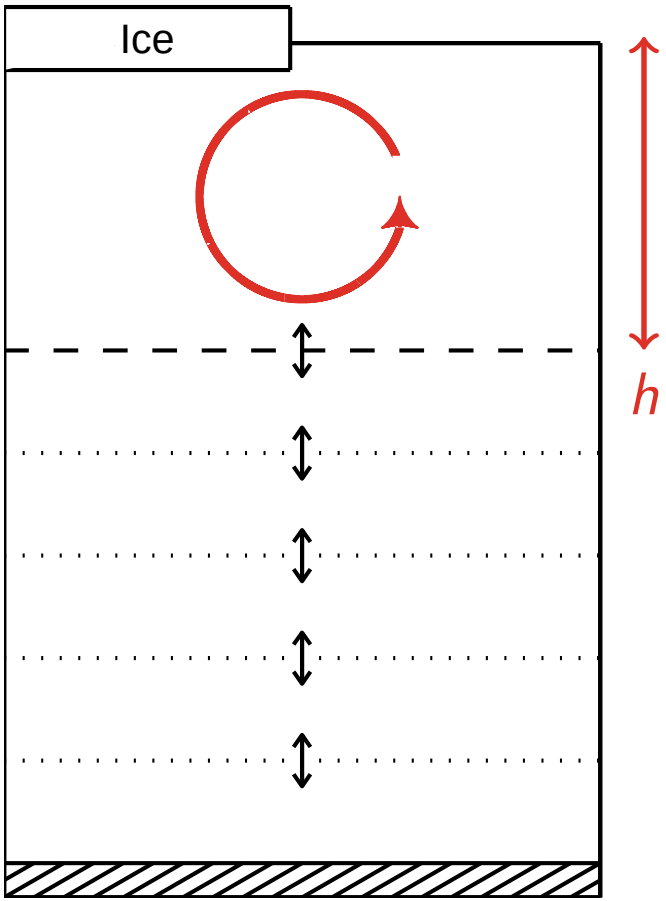
$$PO_4^* = \left[PO_4^{3-}\right] + \frac{[O_2]}{170} - 1.95\mu\text{mol kg}^{-1}$$



- O_2:P conservative with respect to biology.

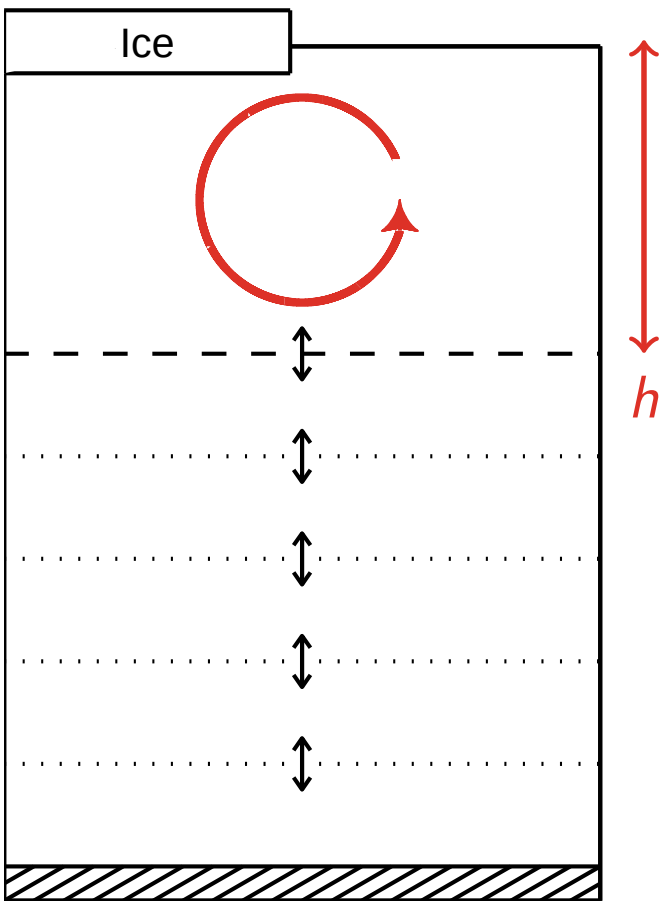
  Gas exchange leads to O_2 deficit in summer.

Stratification

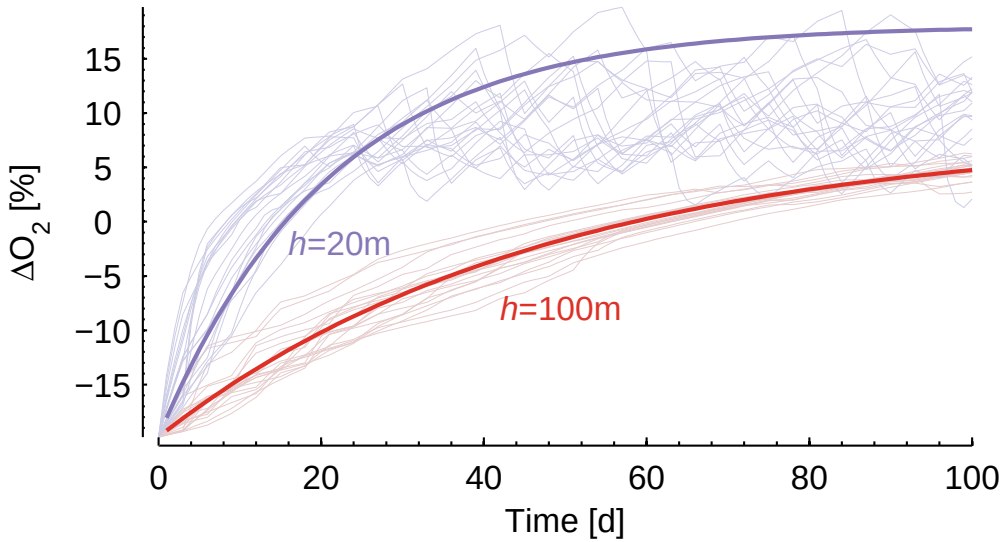


$$h\frac{\partial C}{\partial t} = J_{phy} + J_{gas} + J_{ncp}$$

Stratification



$$k = \frac{\text{piston velocity}}{h}$$

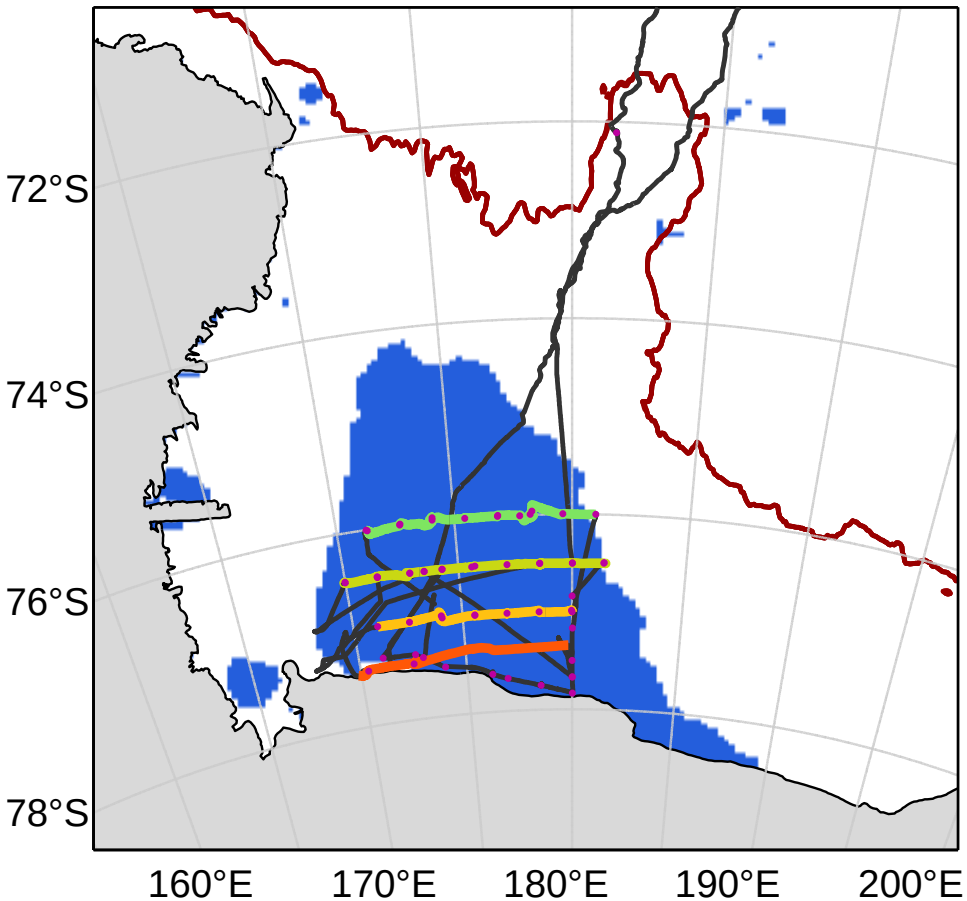


Box model: NCP = constant, stochastic wind.

Analytical expression:

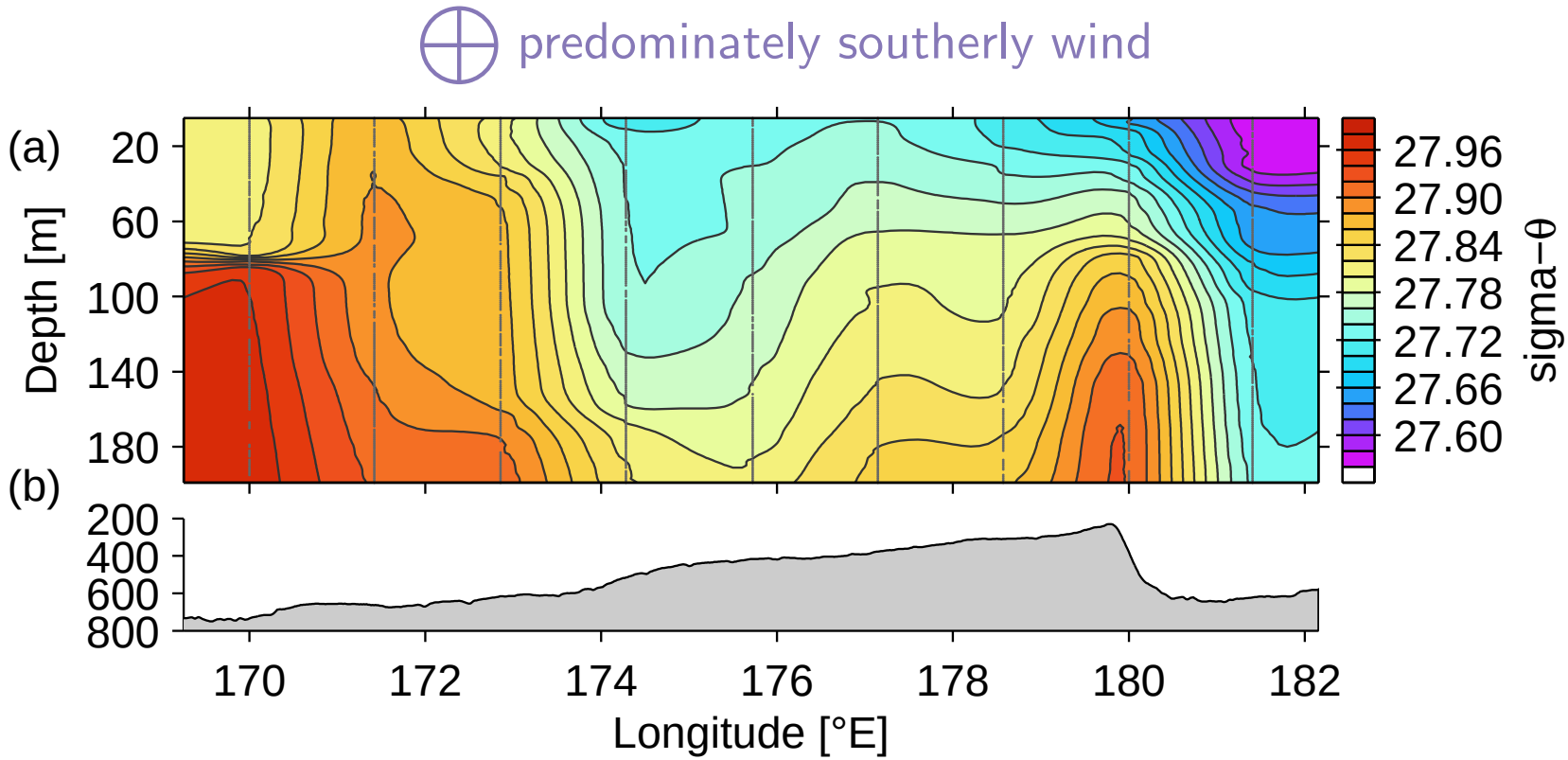
$$O_2(t) = O_{2,sat}\left(1 + \Delta O_{2,i}\right) e^{-kt} - \frac{NCP/h - kO_{2,sat}}{k}\left(1 - e^{-kt}\right)$$

Dynamical stratification in early Spring



NBP06-08, spring cruise

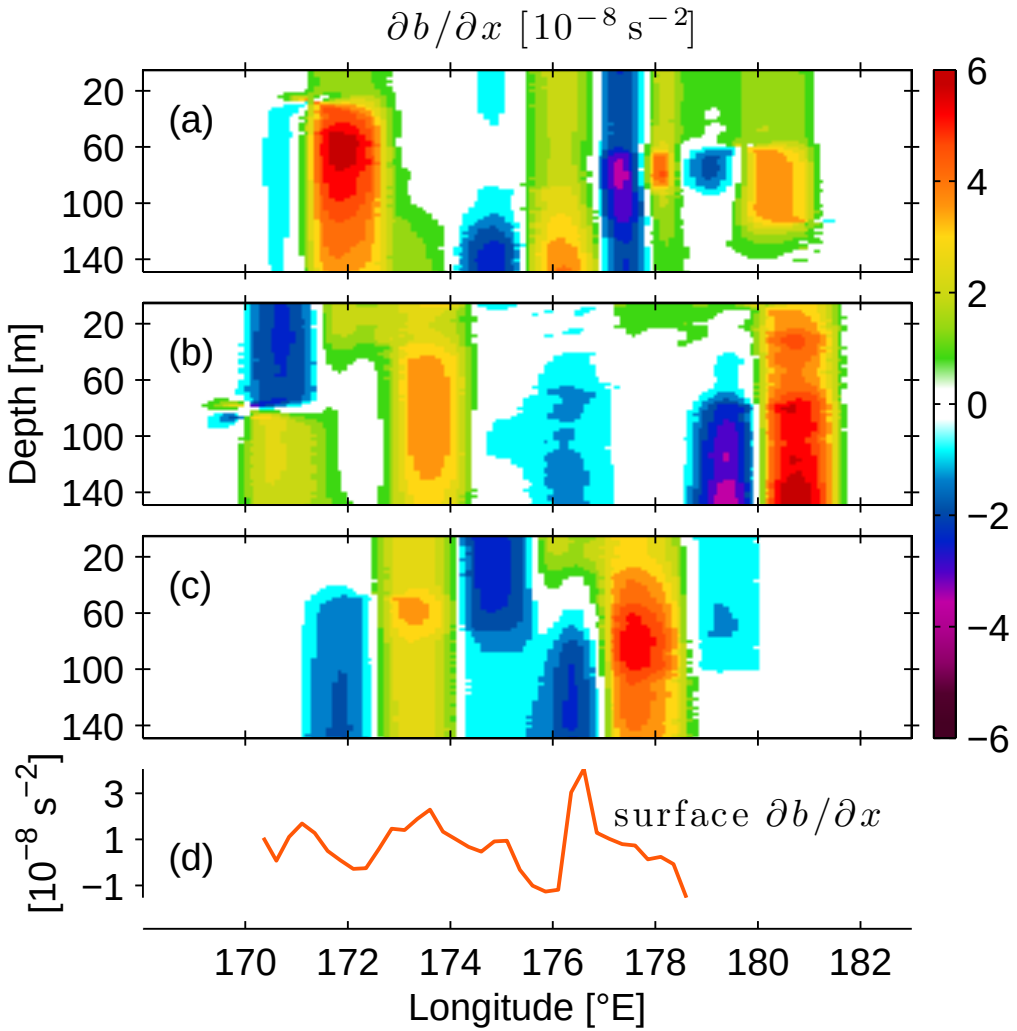
Dynamical stratification in early Spring



Spring water column observations

Dynamical stratification in early Spring

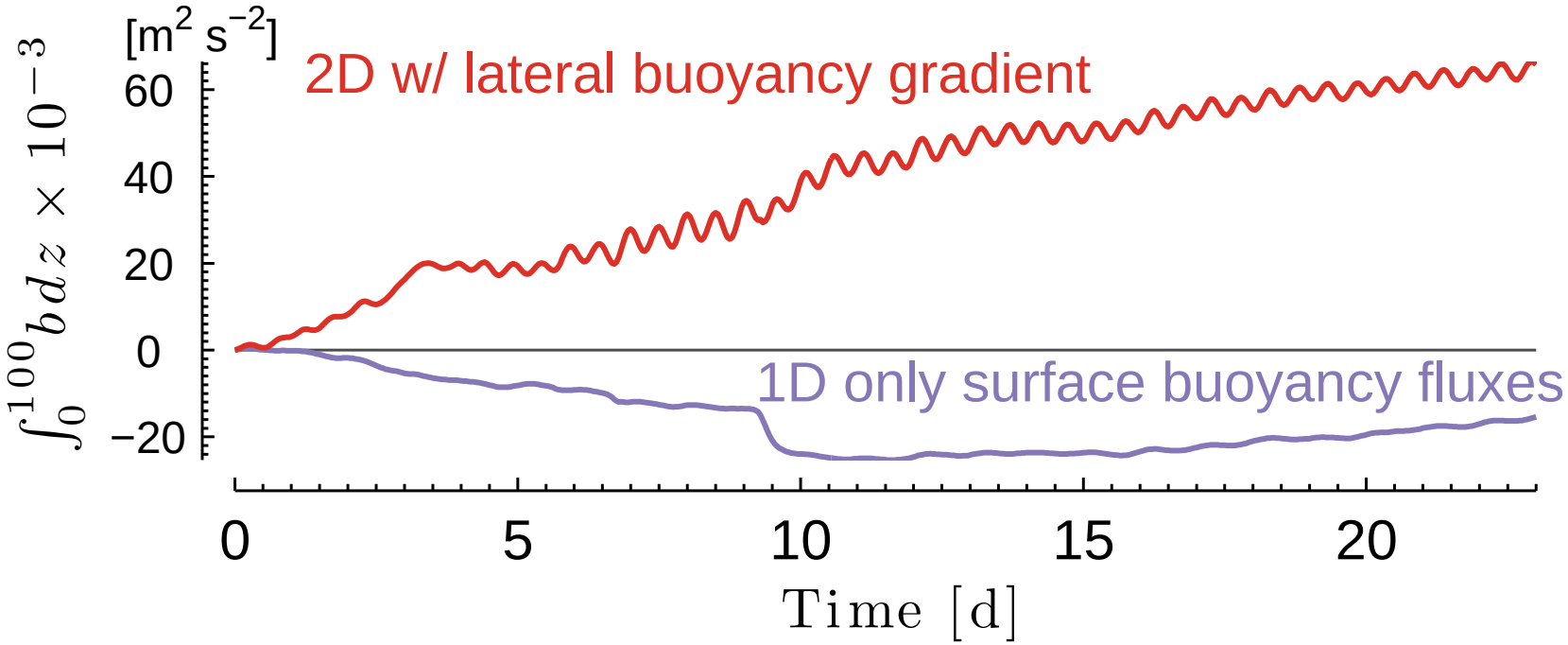
Fronts



$$b = -g\rho/\rho_o$$

Dynamical stratification in early Spring

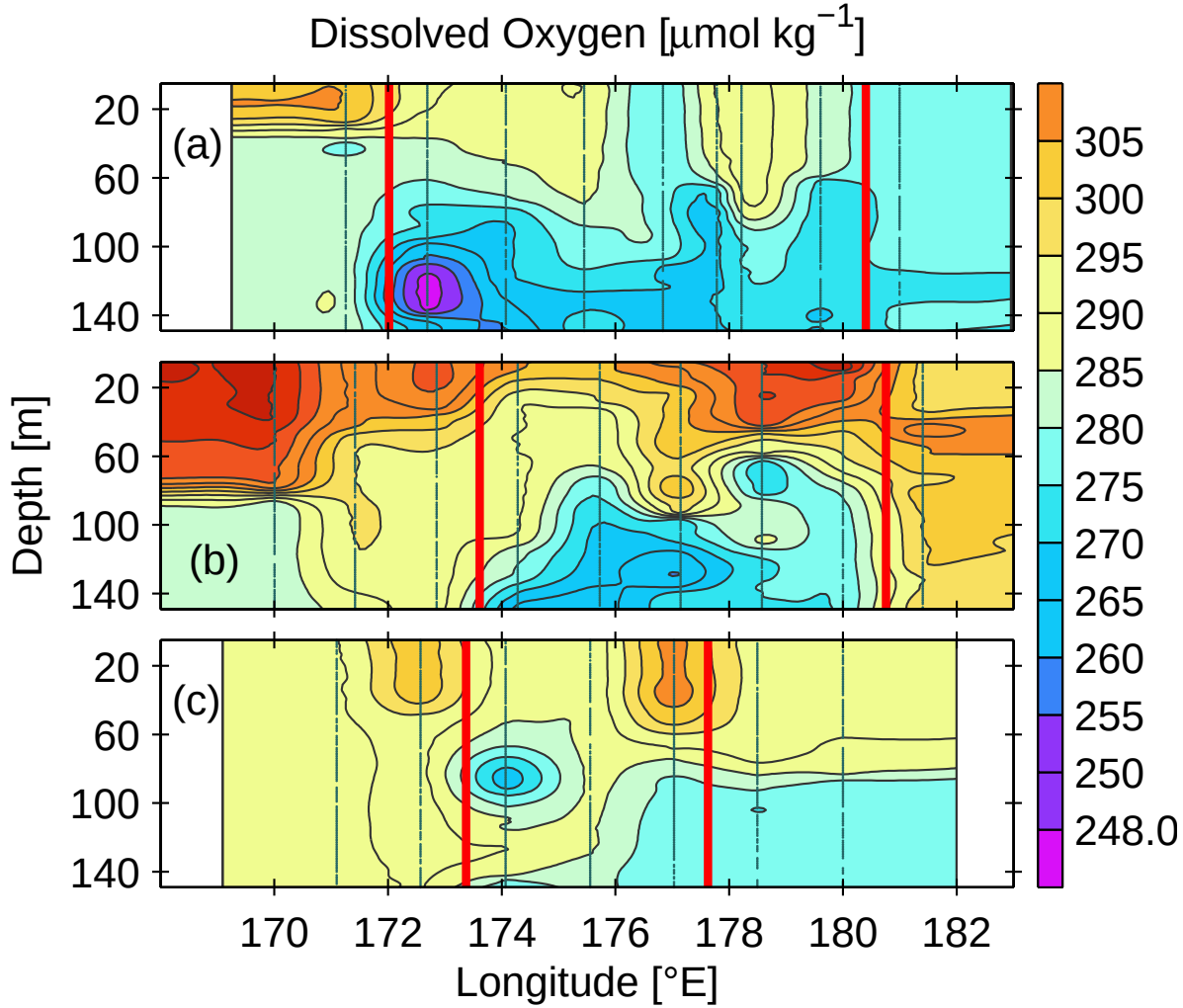
Buoyancy generation



ROMS simulation results

Dynamical stratification in early Spring

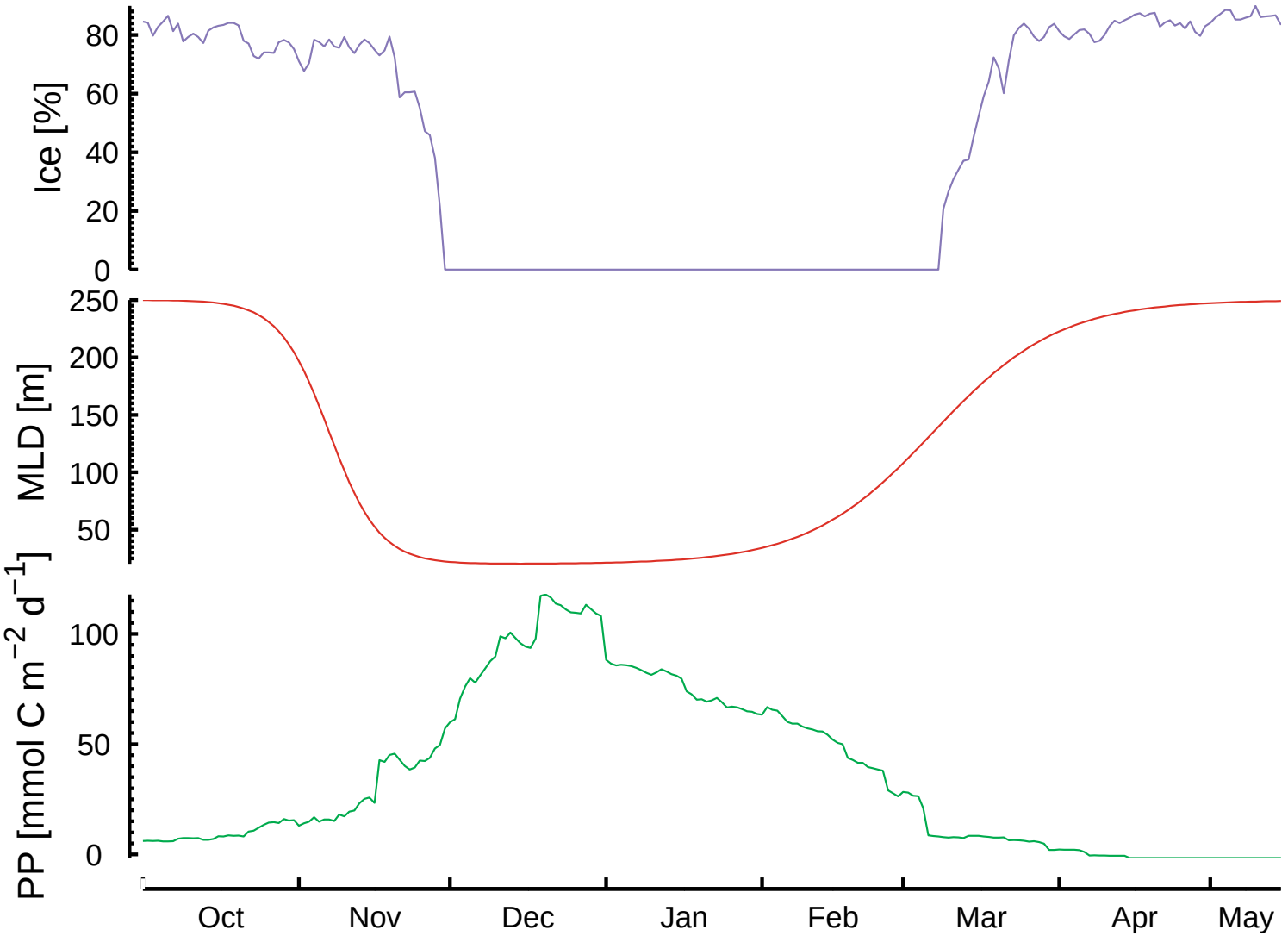
Enhanced winter-spring transition at fronts



Spring water column observations

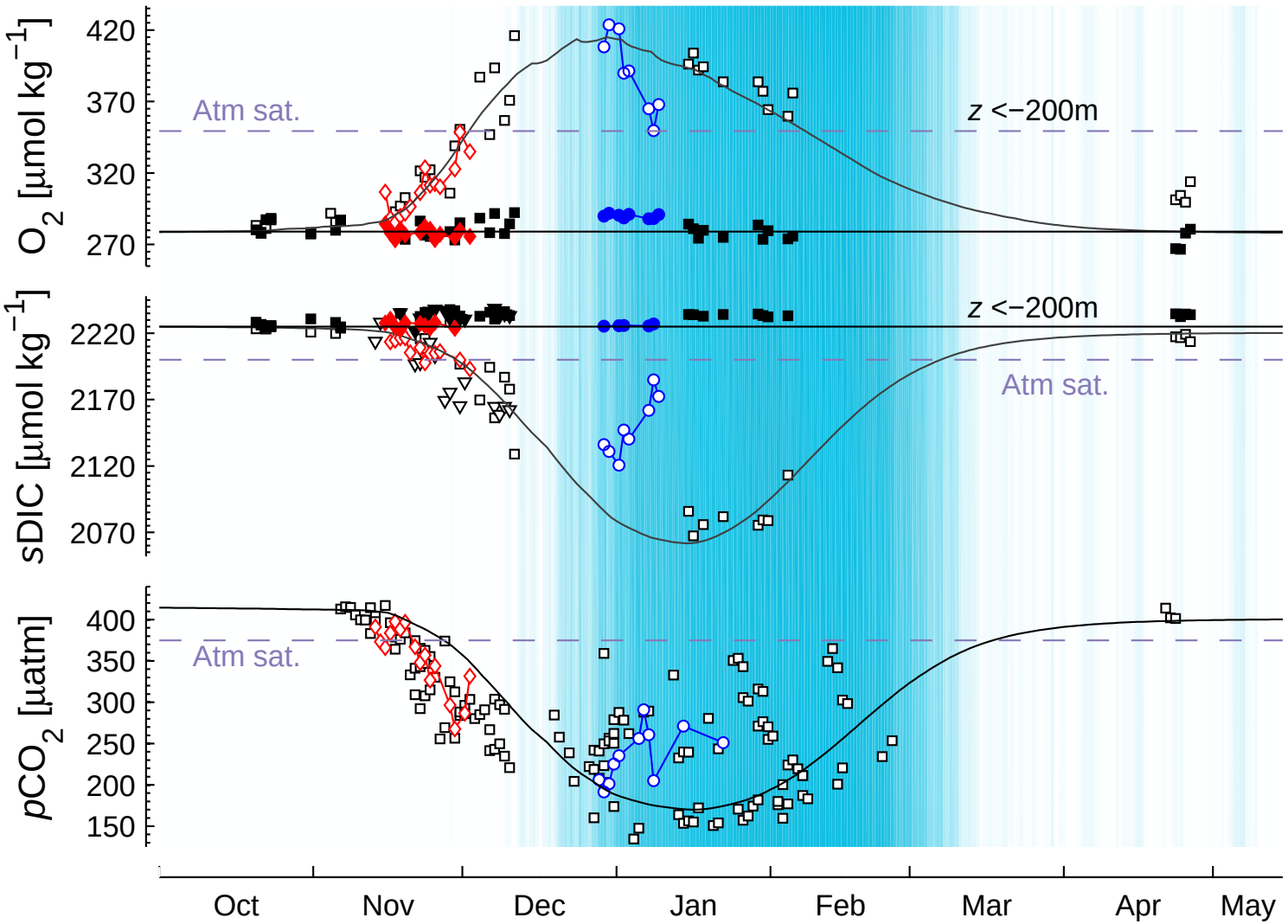
Annual sink dynamics

Forcing



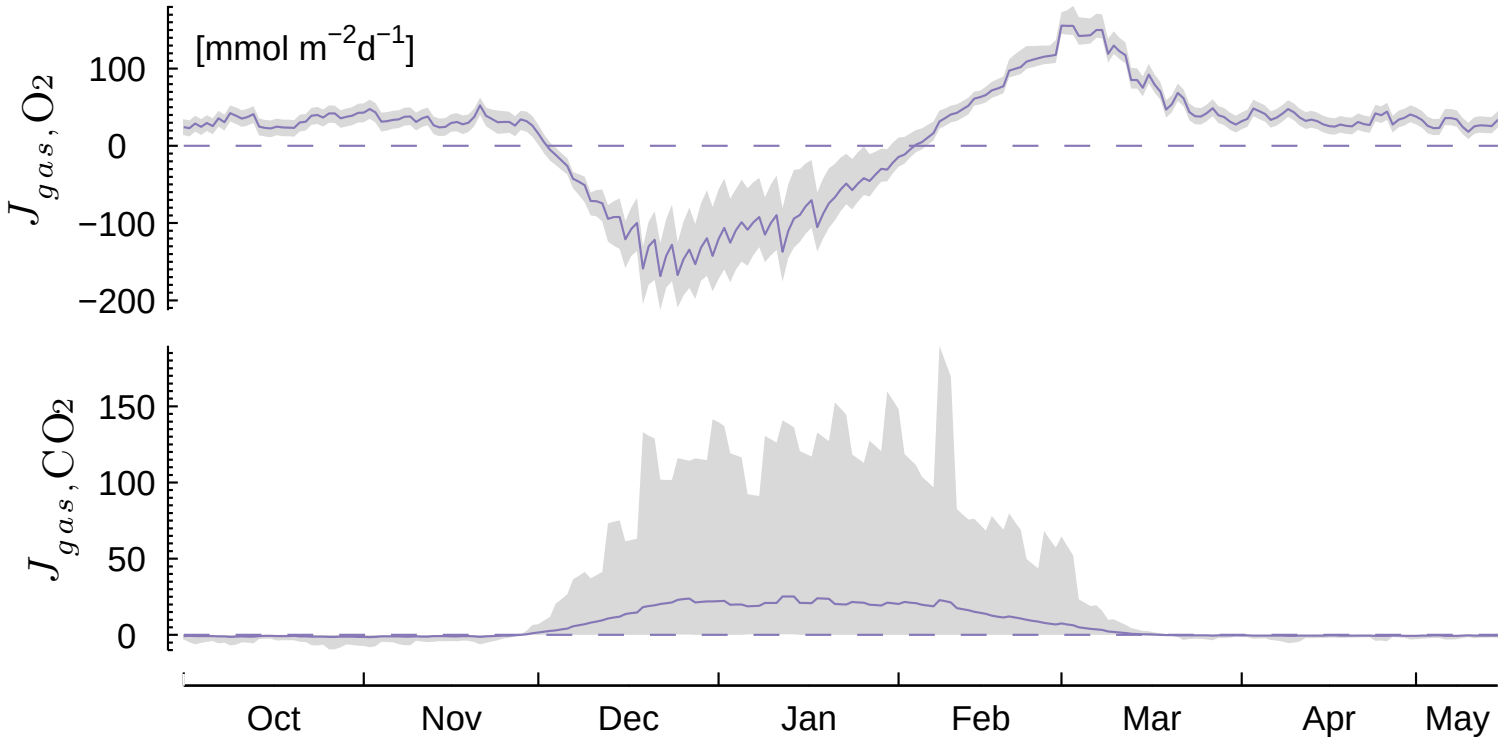
Annual sink dynamics

Upper ocean properties



Annual sink dynamics

Fluxes



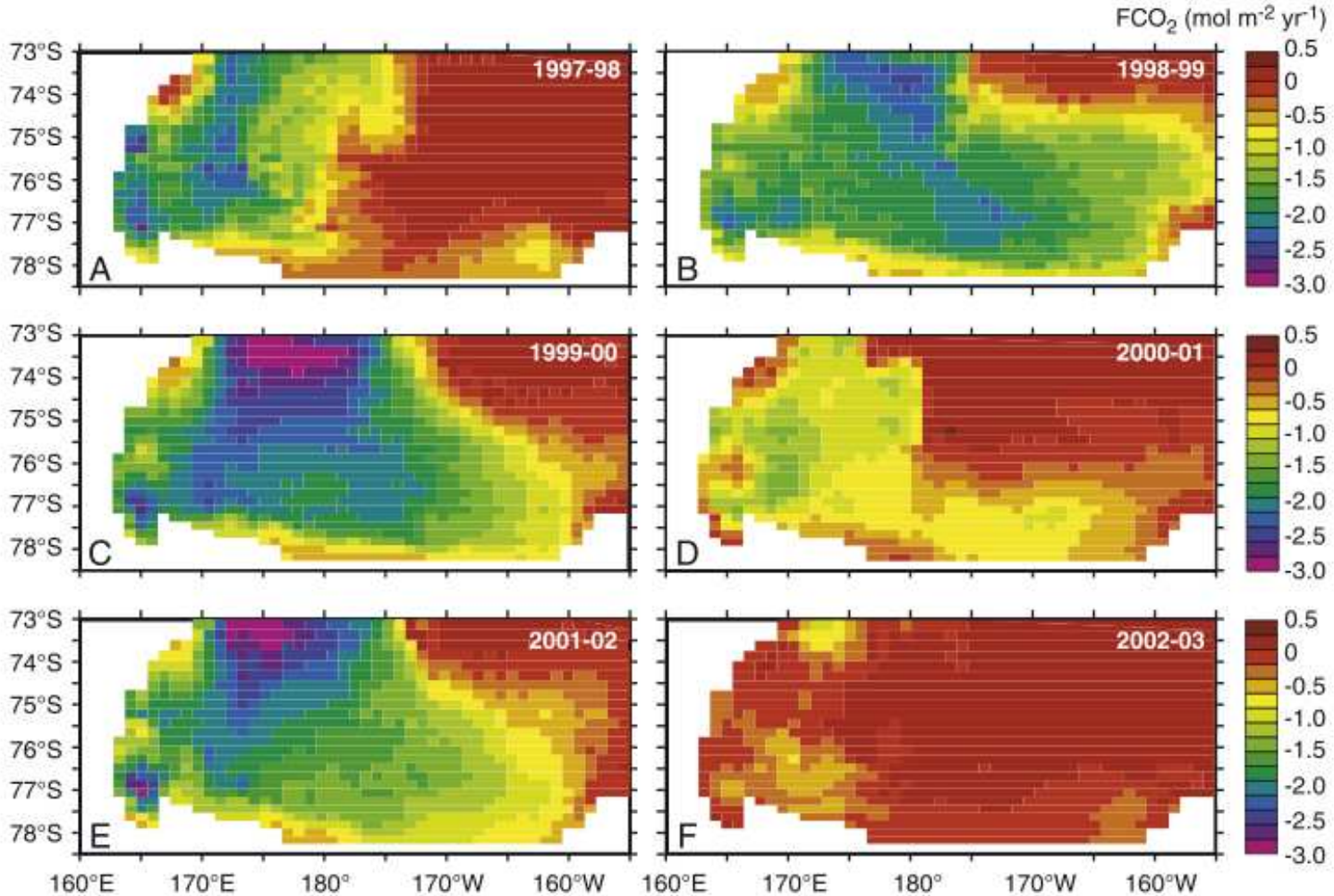
Net sink for both O_2 and CO_2

$$\int J_{gas,O_2}\, dt = 110 \text{ mol m}^{-2}$$

$$\int J_{gas,CO_2}\, dt = 1.4 \text{ mol m}^{-2}$$

Annual sink dynamics

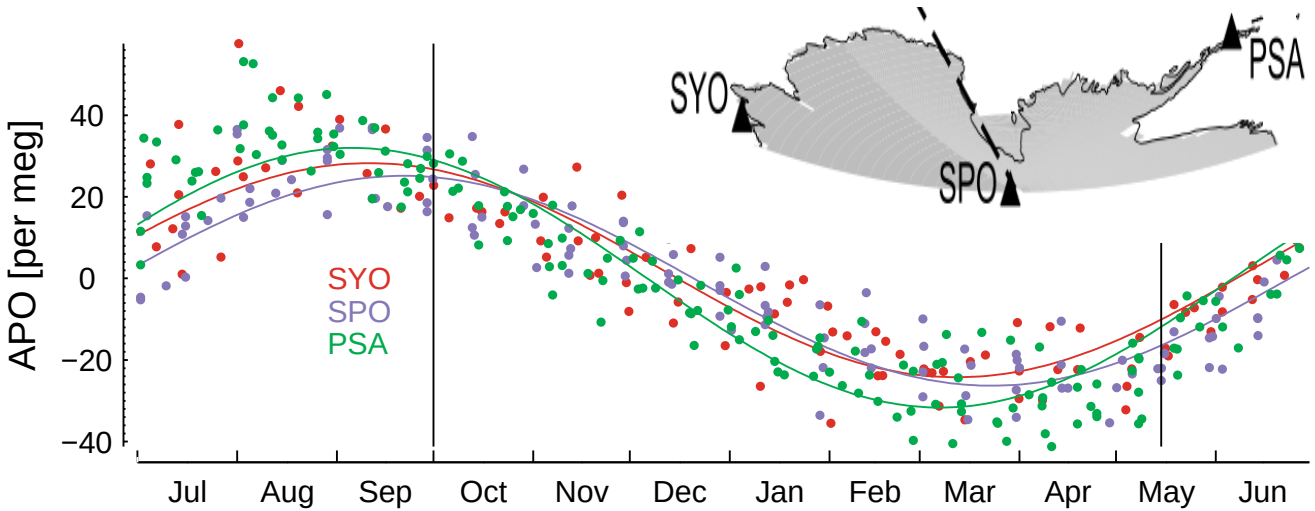
Interannual variability (sign convention reversed)

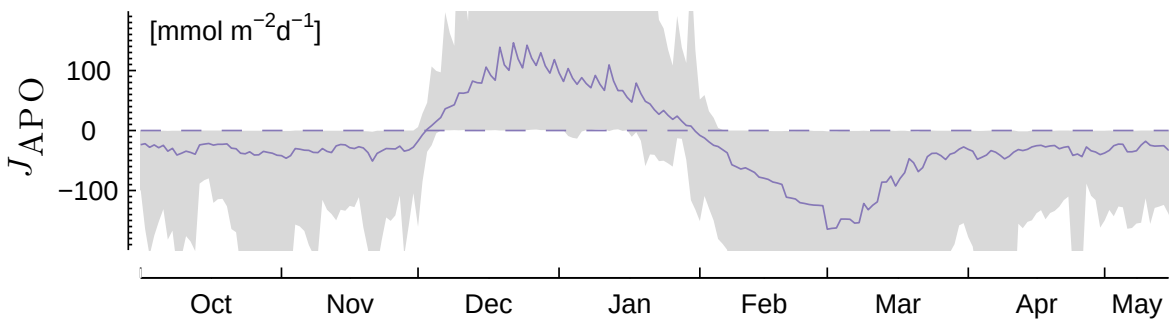


Arrigo & Van Dijken 2007

Influence on the atmosphere

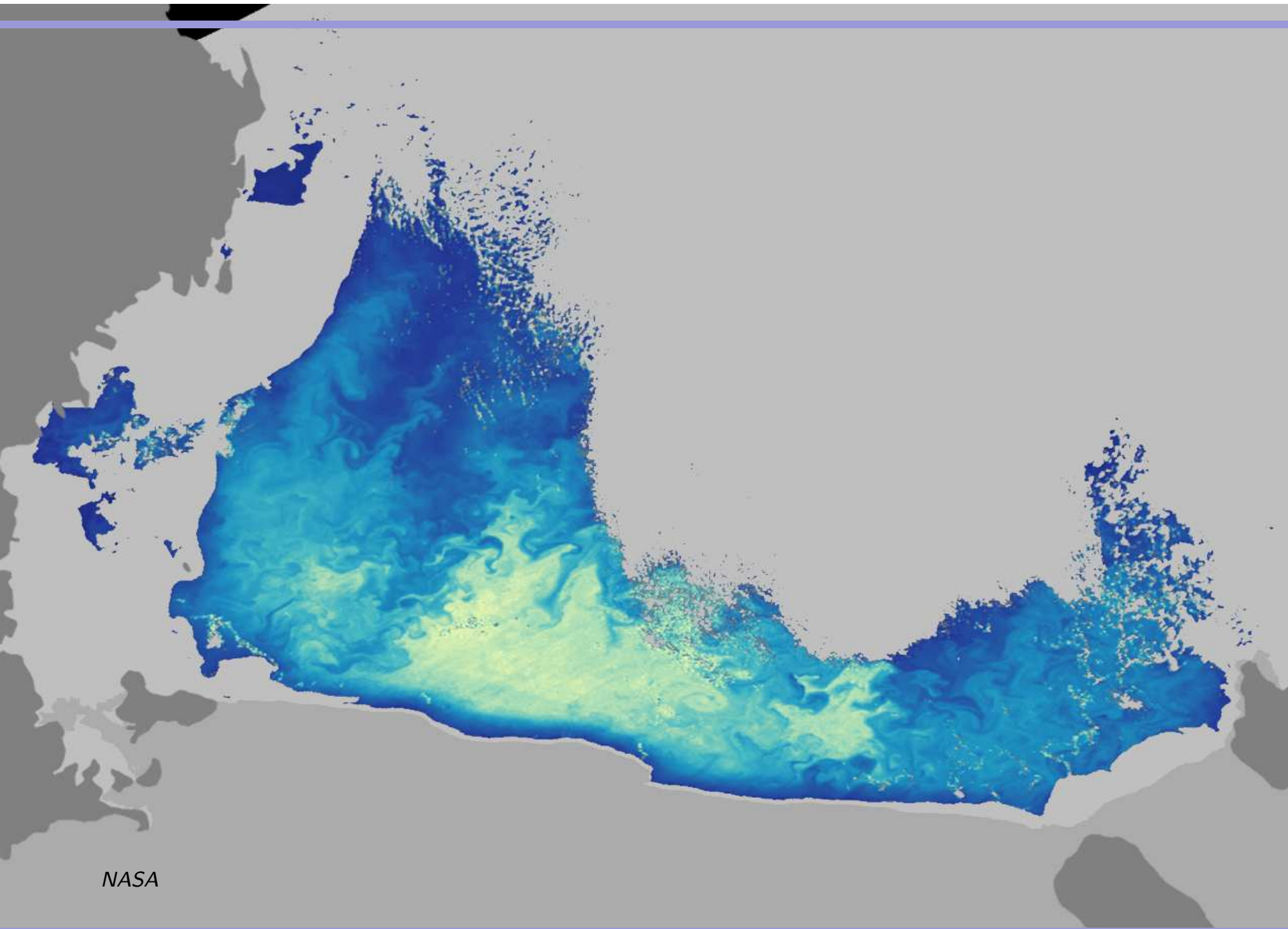
Atmospheric potential oxygen





$$J_{\mathrm{APO}} = -J_{gas,\mathrm{O_2}} - 1.1 J_{gas,\mathrm{CO_2}}$$

APO is mostly conservative with respect to the terrestrial biosphere and fossil fuel emissions.
Battle et al. 2008

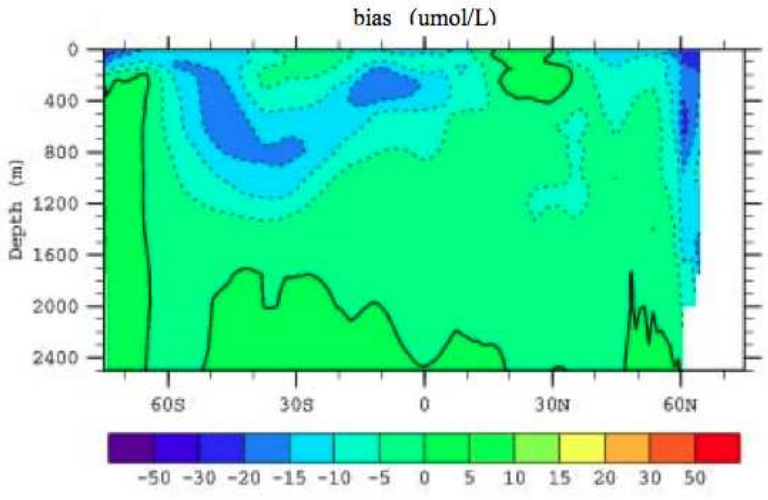


NASA

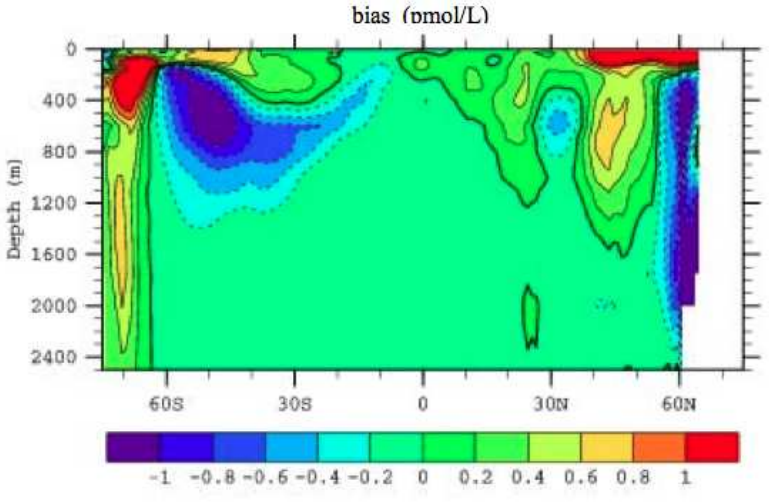
Representing heterogeneity

Model biases

Anthropogenic CO_2 (μmol l^{-1})

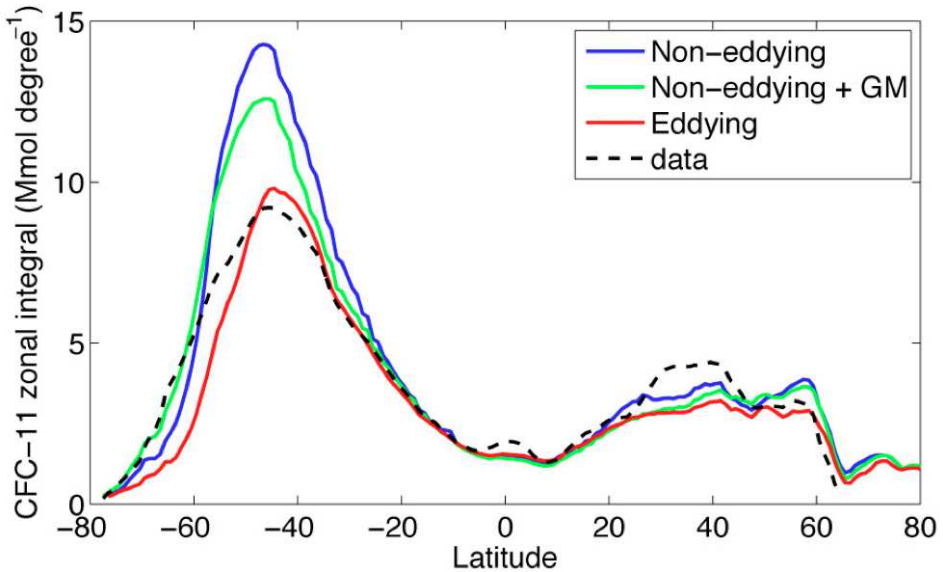


CFC-11 (μmol l^{-1})

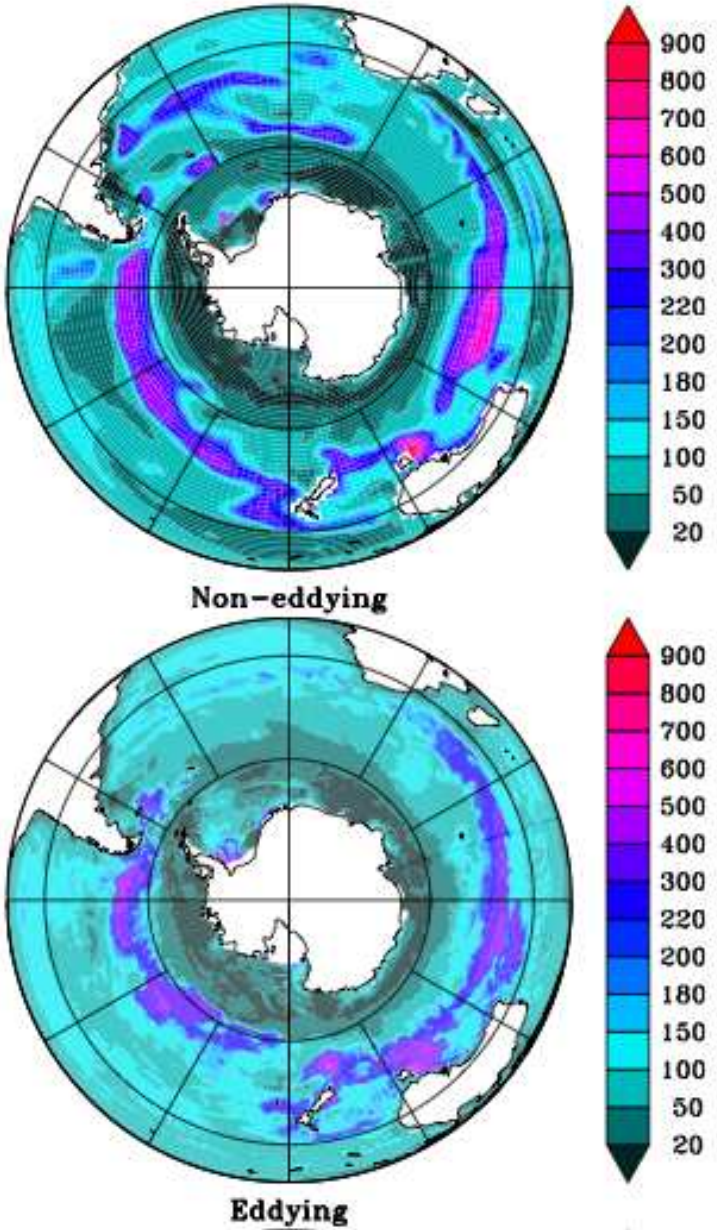


Thorten et al. 2009

Representing heterogeneity



Lachkar et al. 2007



Questions?