Closing the Meridional Overturning Circulation through Southern Ocean Upwelling

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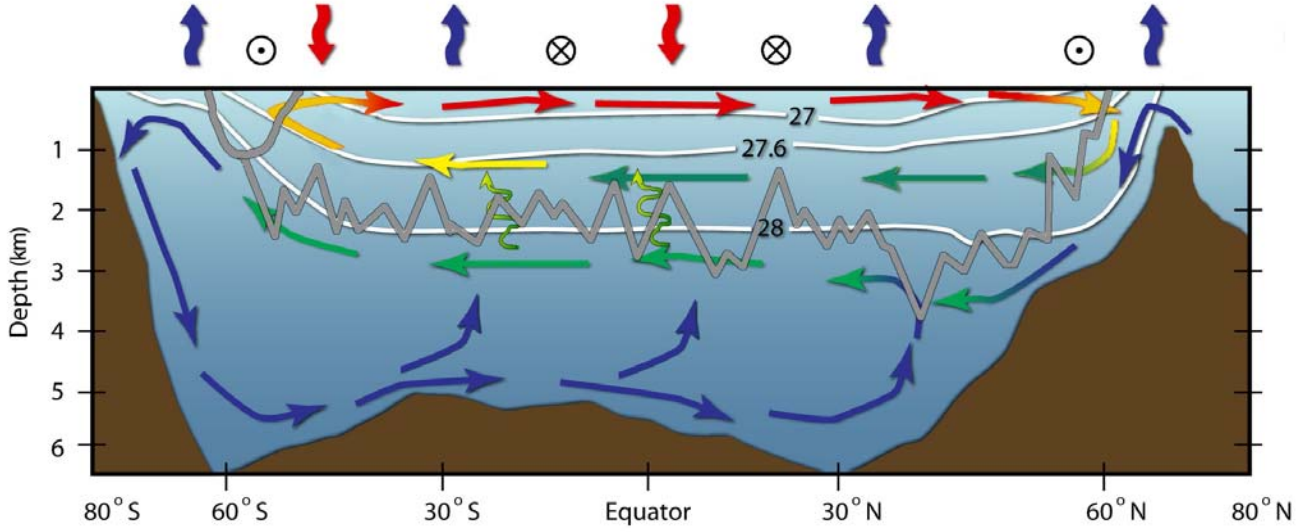
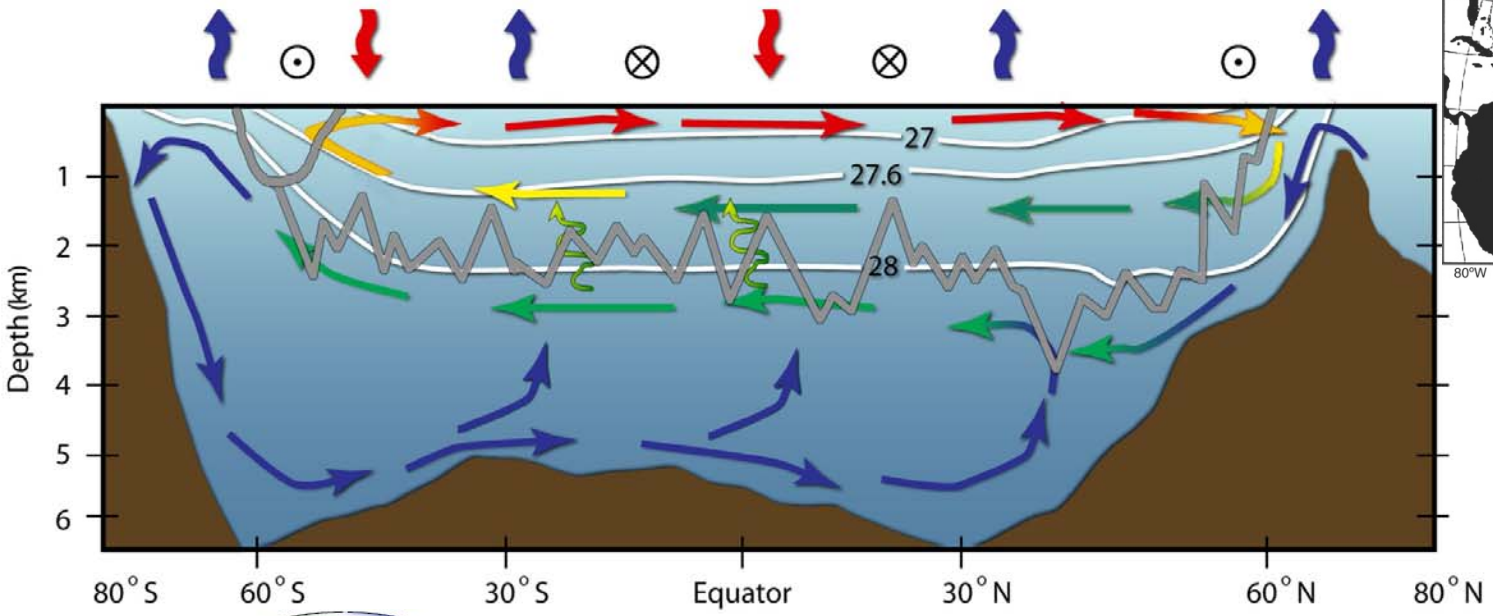
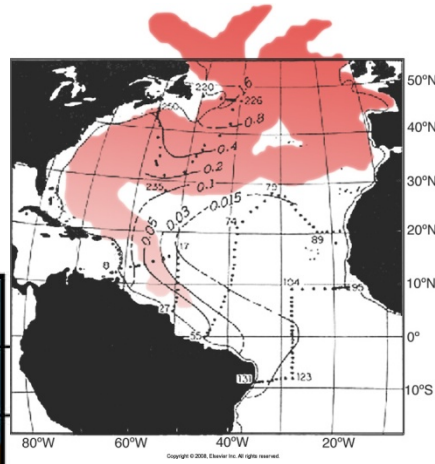
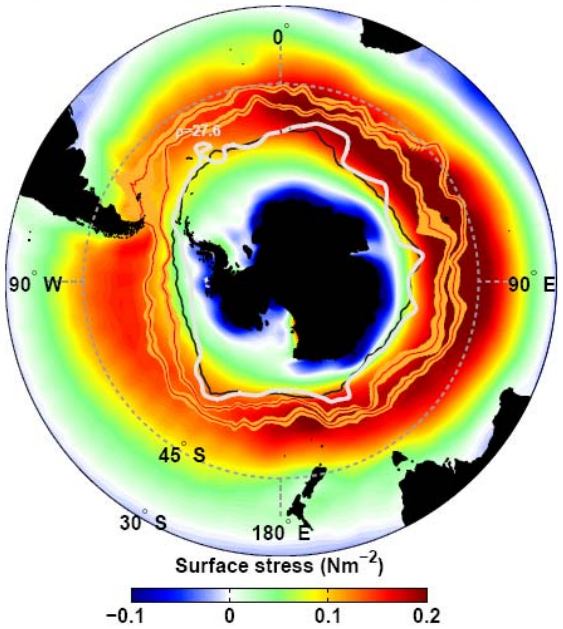


Schematic of Ocean's MOC

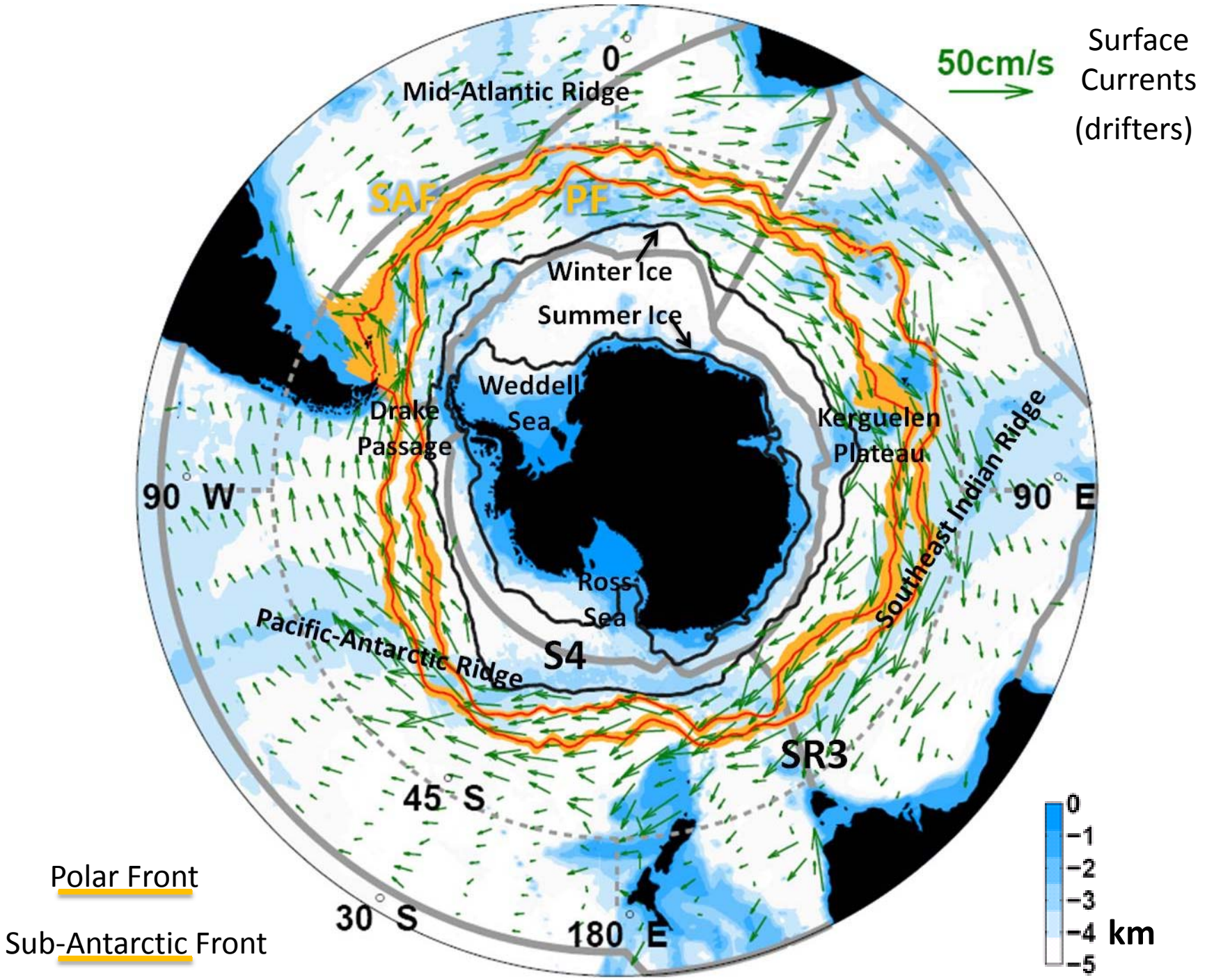




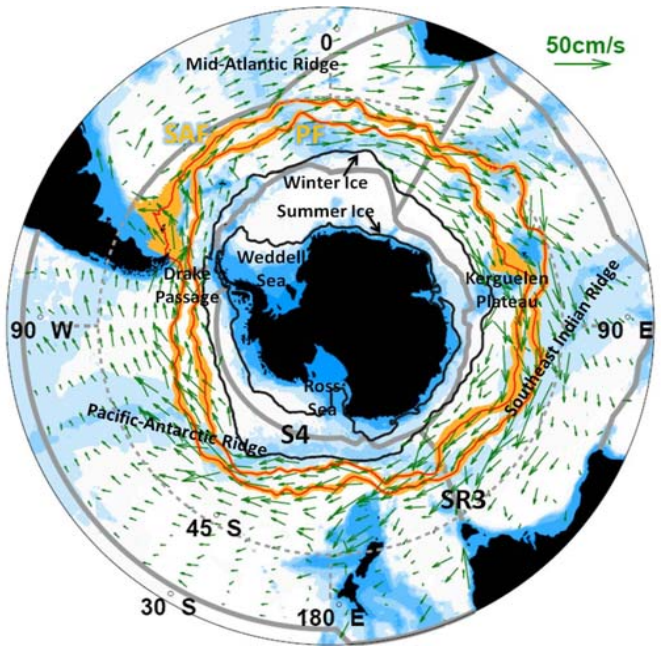


Upwelling in Southern Ocean controls communication between atmosphere and reservoirs of heat and carbon in ocean interior

Important implications for paleo climate and climate variability


50cm/s
Surface Currents (drifters)
0°
Mid-Atlantic Ridge
SAF
PF
Winter Ice
Summer Ice
Weddell Sea
Drake Passage
Kerguelen Plateau
Southeast Indian Ridge
90° W
90° E
Ross Sea
Pacific-Antarctic Ridge
S4
SR3
45° S
30° S
180° E
Polar Front
Sub-Antarctic Front
0
−1
−2
−3
−4
−5
km

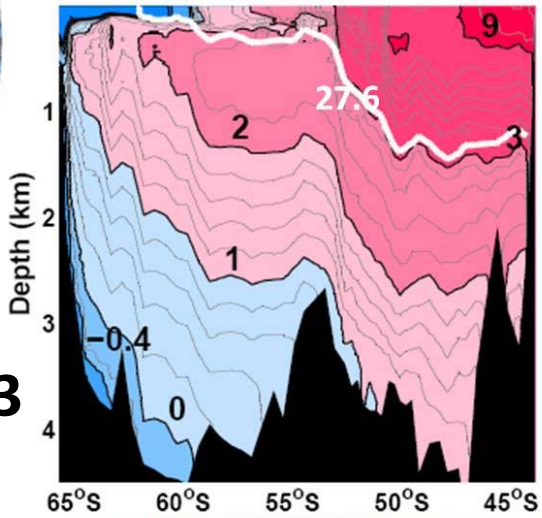
Hydrography

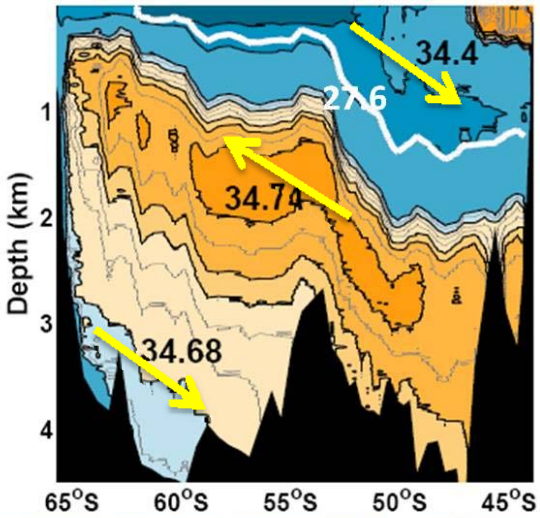


Temperature

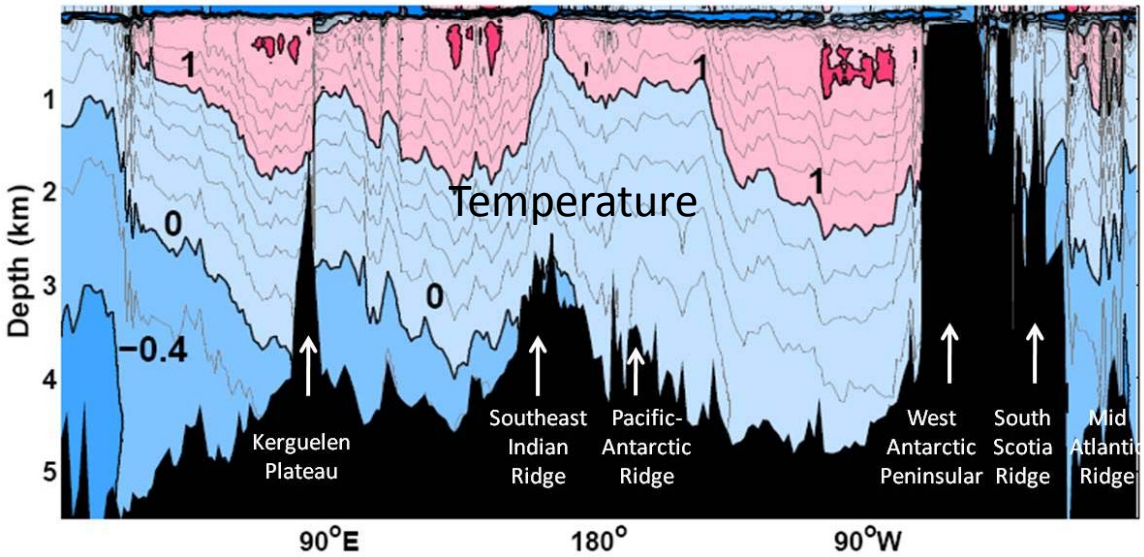
Salinity

SR3

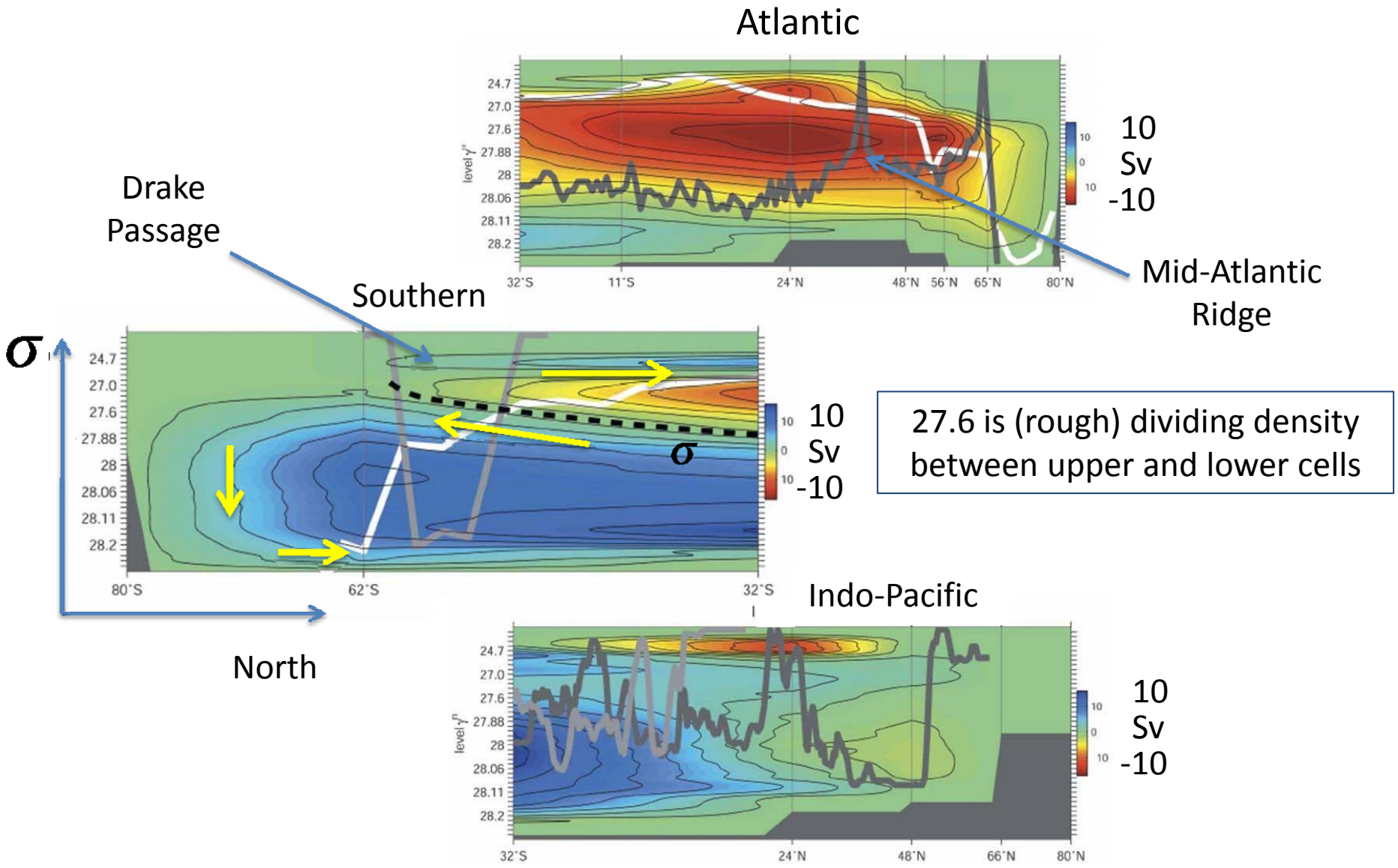




S4



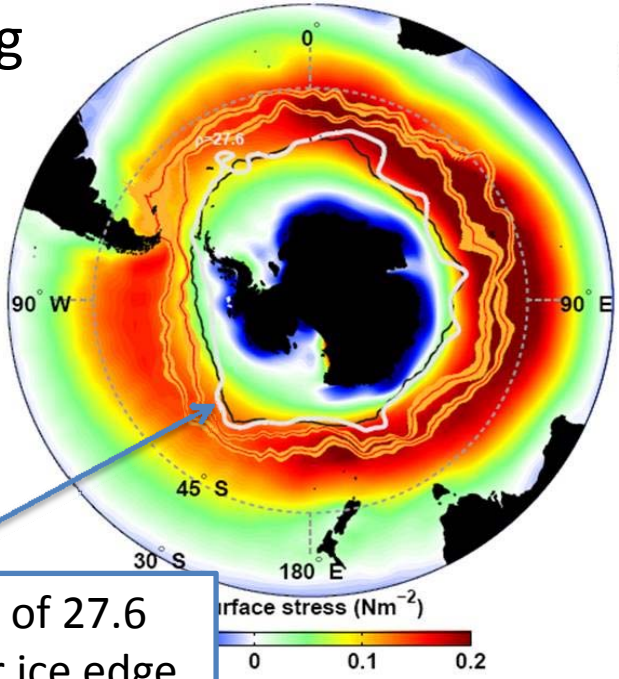
Inversions for the Ocean's MOC



Lumpkin and Speer, 2007

Surface Forcing

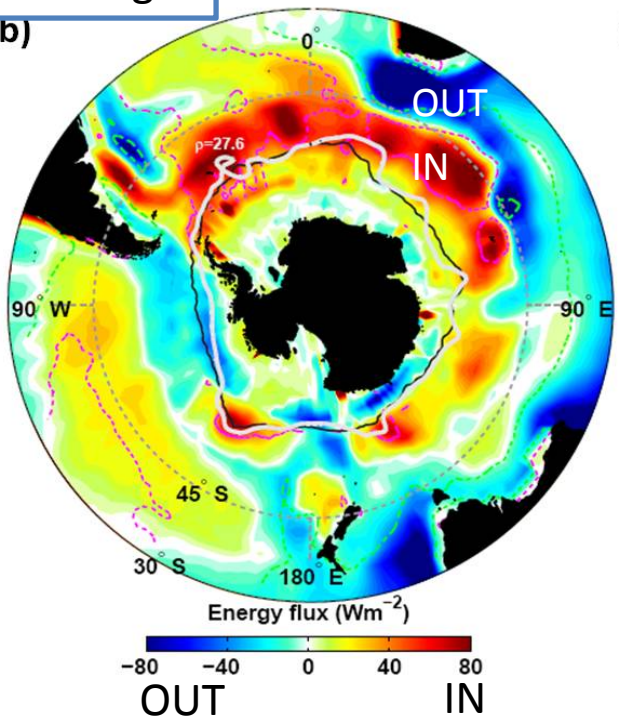
Zonal
Wind Stress



Note coincidence of 27.6 outcrop and winter ice edge

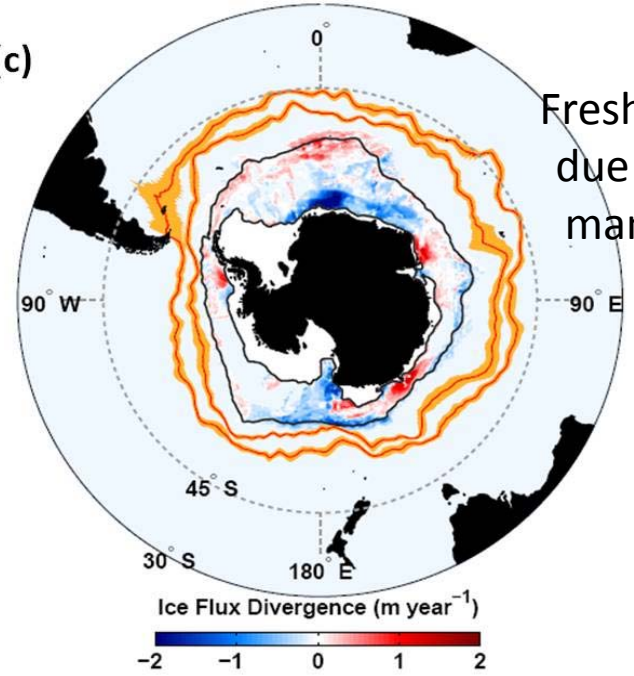
(b)

Net surface buoyancy flux



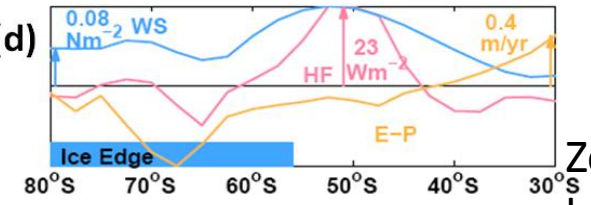
(c)

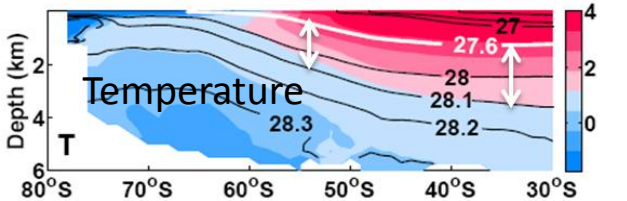
Freshwater flux due to sea ice manufacture

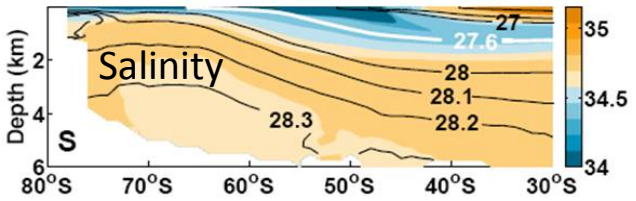


(d)

Zonal-average hydrography

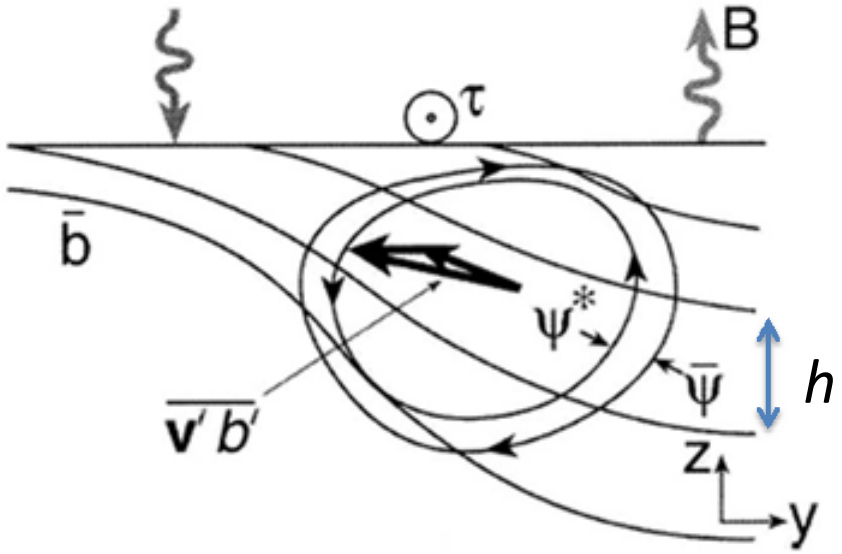






Dynamical Ideas

Marshall and Radko, 2003

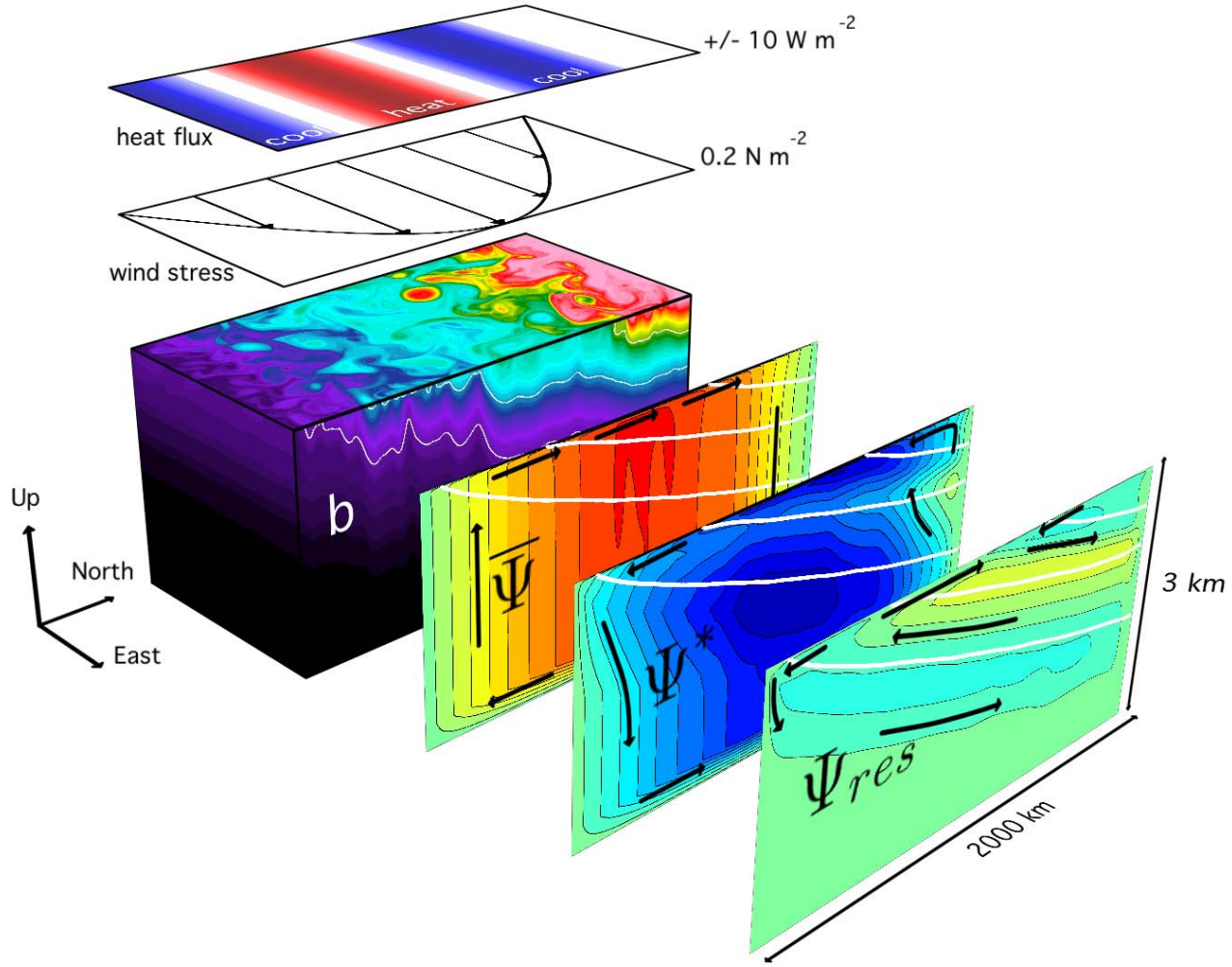


$$\underbrace{v_{res}\bar{h}}_{\psi_{res}} = \overline{vh} = \underbrace{\bar{v}\bar{h}}_{\bar{\psi}} + \underbrace{\overline{v'h'}}_{\psi^*}$$

Residual Circulation

Cancellatory

Eddying Channel



Background theory

Residual-mean momentum equation in density coordinates

$$-\rho_0 f \overline{vh} = \overline{F}_{eddy} + \overline{F}_{wind} - \frac{\Delta P}{L_x}$$

Eddy PV flux

$$\overline{F}_{eddy} = \rho_0 \overline{h}^2 \overline{v'Q'}$$

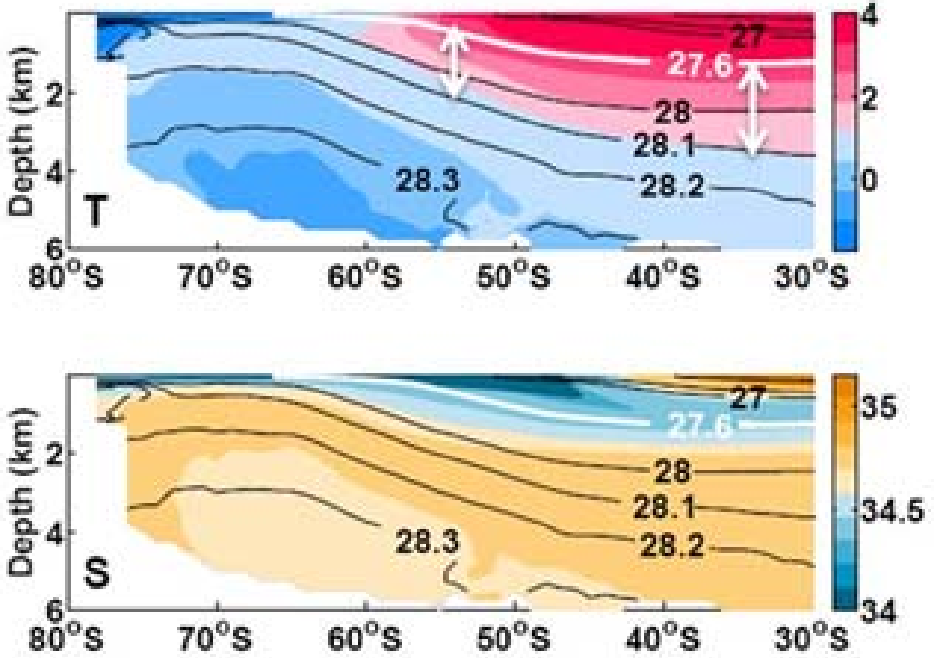
Ertel PV

$$Q = \frac{f+\zeta}{h}$$

In interior, above topography

$$\overline{vh} = -\frac{\overline{h}^2}{f}\overline{v'Q'}$$

$$= \frac{\overline{h}^2}{f} K \frac{\partial \overline{Q}}{\partial y} = -K \frac{\partial \overline{h}}{\partial y}$$



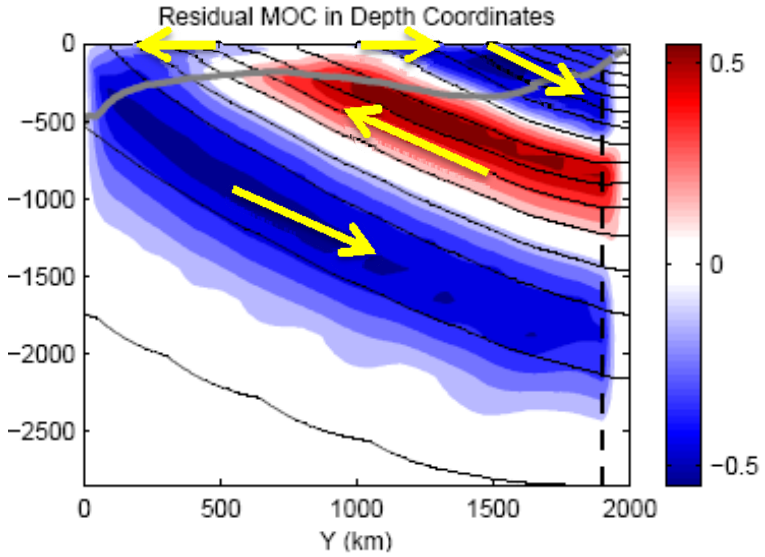
K of $10^3\ \mathrm{m^2\,s^{-1}}$

isopycnal slope of $\sim 0.5 \times 10^{-3}$

$L_x \sim 20{,}000\,\mathrm{km}$

$\overline{vh}^x \sim 10\mathrm{Sv}$

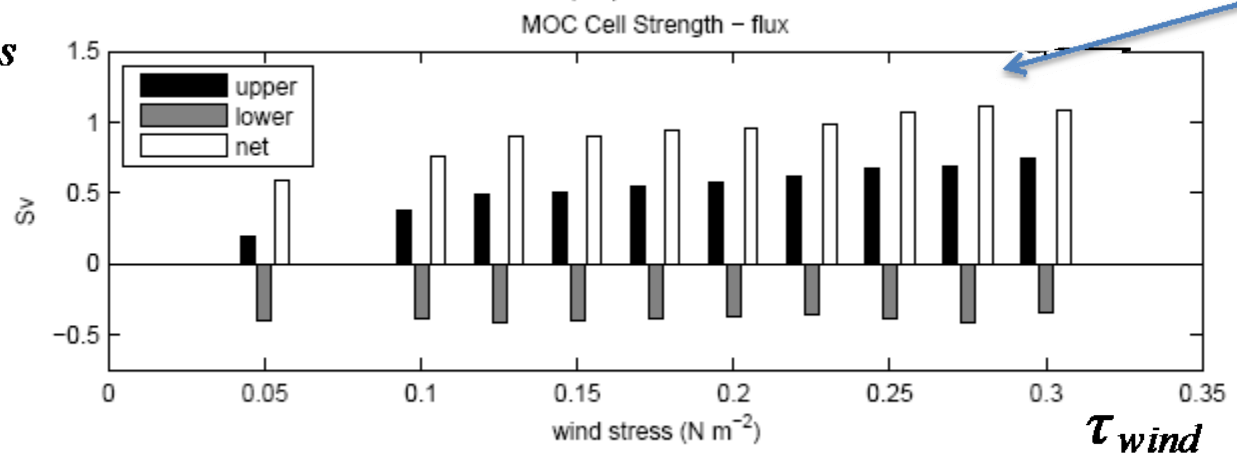
Response of the MOC to changing winds



Ryan Abernathey, MIT

Eddy saturation regime
cf Henning and Vallis, 2005

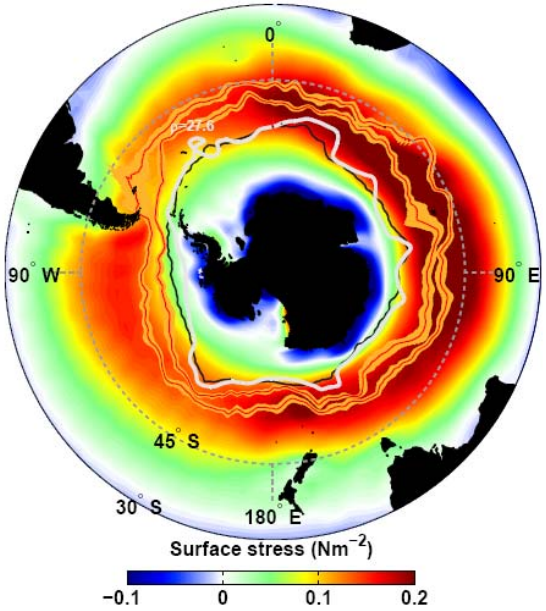
ψ_{res}

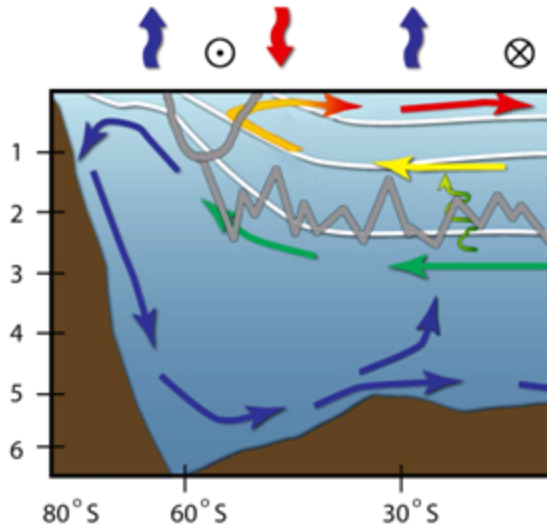


$$\delta\psi_{res} = -\frac{\delta\tau}{f} + K\delta S + \delta K S$$

compensate

Conclusions and questions





Southern Ocean upwelling branch of the MOC is a central component of the climate system

1. What is the predictability of the ACC and its overturning circulation?
2. What is the role of the upwelling branch of the MOC in modulating winter sea-ice extent and visa-versa?
3. How robust is the pattern of air-sea fluxes over the southern ocean? Could it be substantially rearranged?
4. How might the system have operated in the past, how might it change in the future?

Updated Schematic of Ocean's MOC