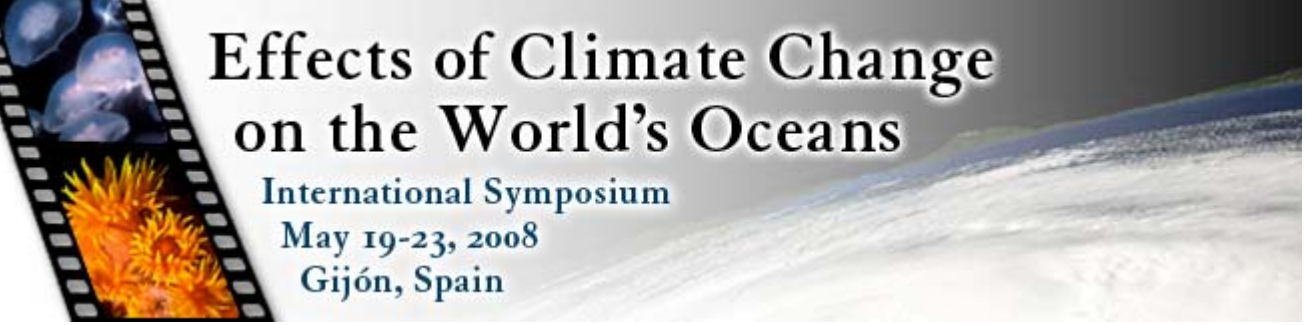

Southern Hemisphere westerly wind control over the ocean's thermohaline circulation

Matthew England *
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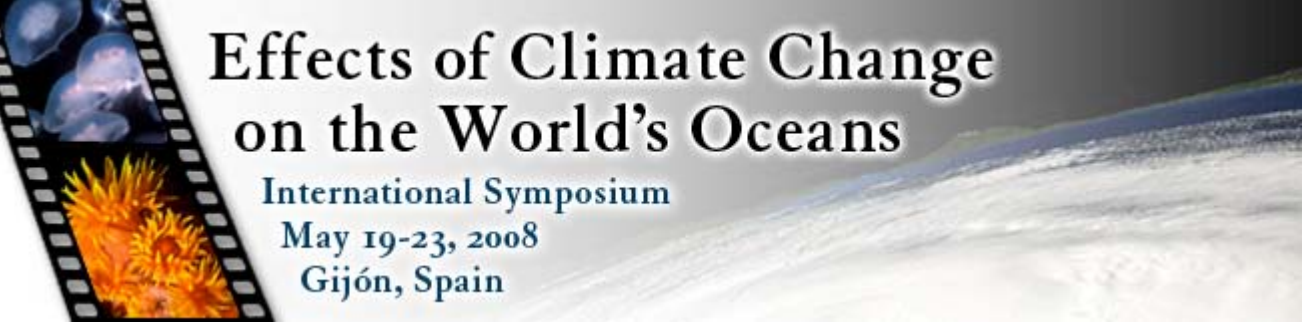
M.England@unsw.edu.au

**** … with Alex Sen Gupta†, Agus Santoso†, Jessica Trevena†, Willem Sijp†, Steve Rintoul*, …***

Climate Change Research Centre



surface flux

Southern Hemisphere ~~westerly wind~~ control over the ocean's thermohaline circulation

Southern

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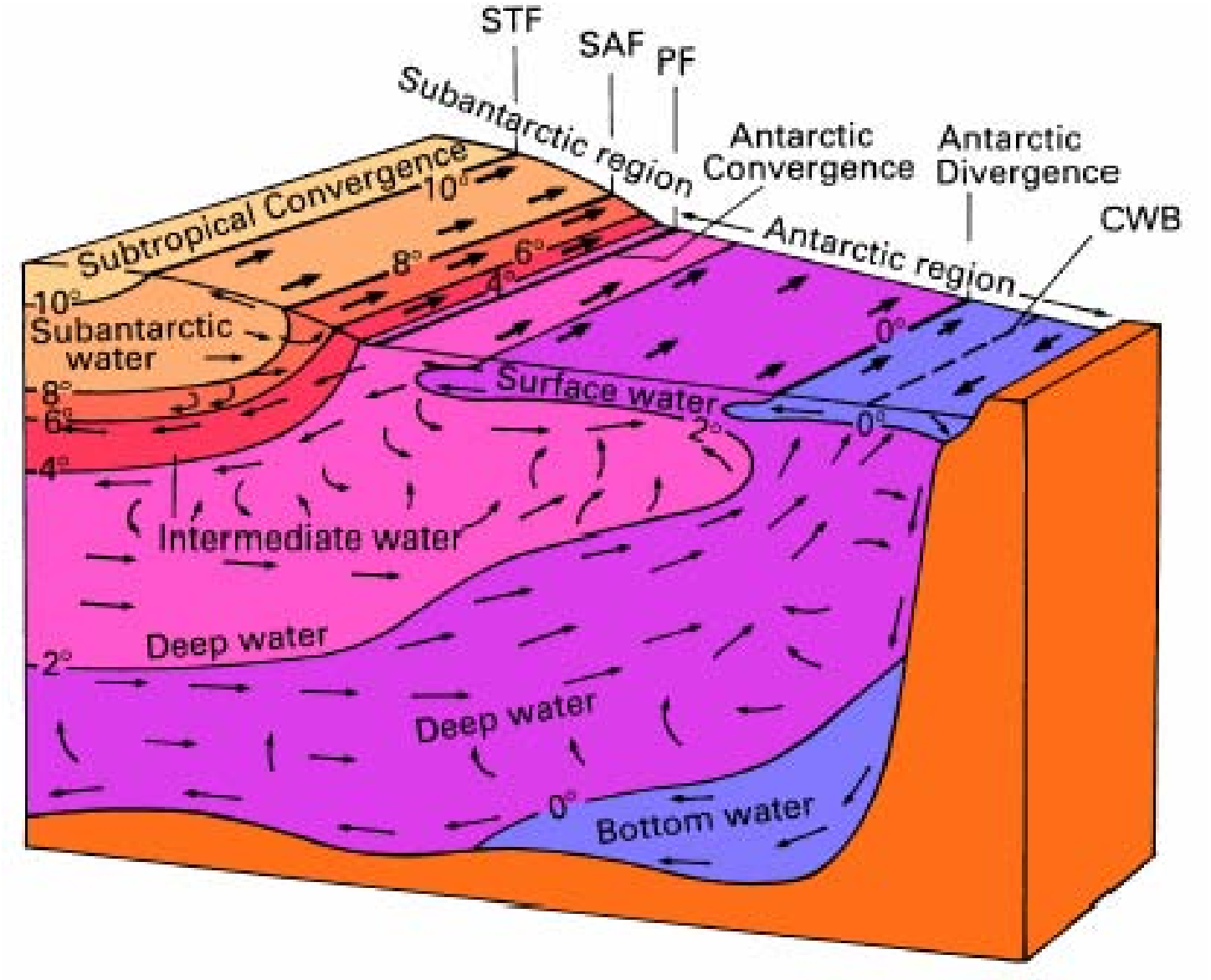
Climate Change Research Centre

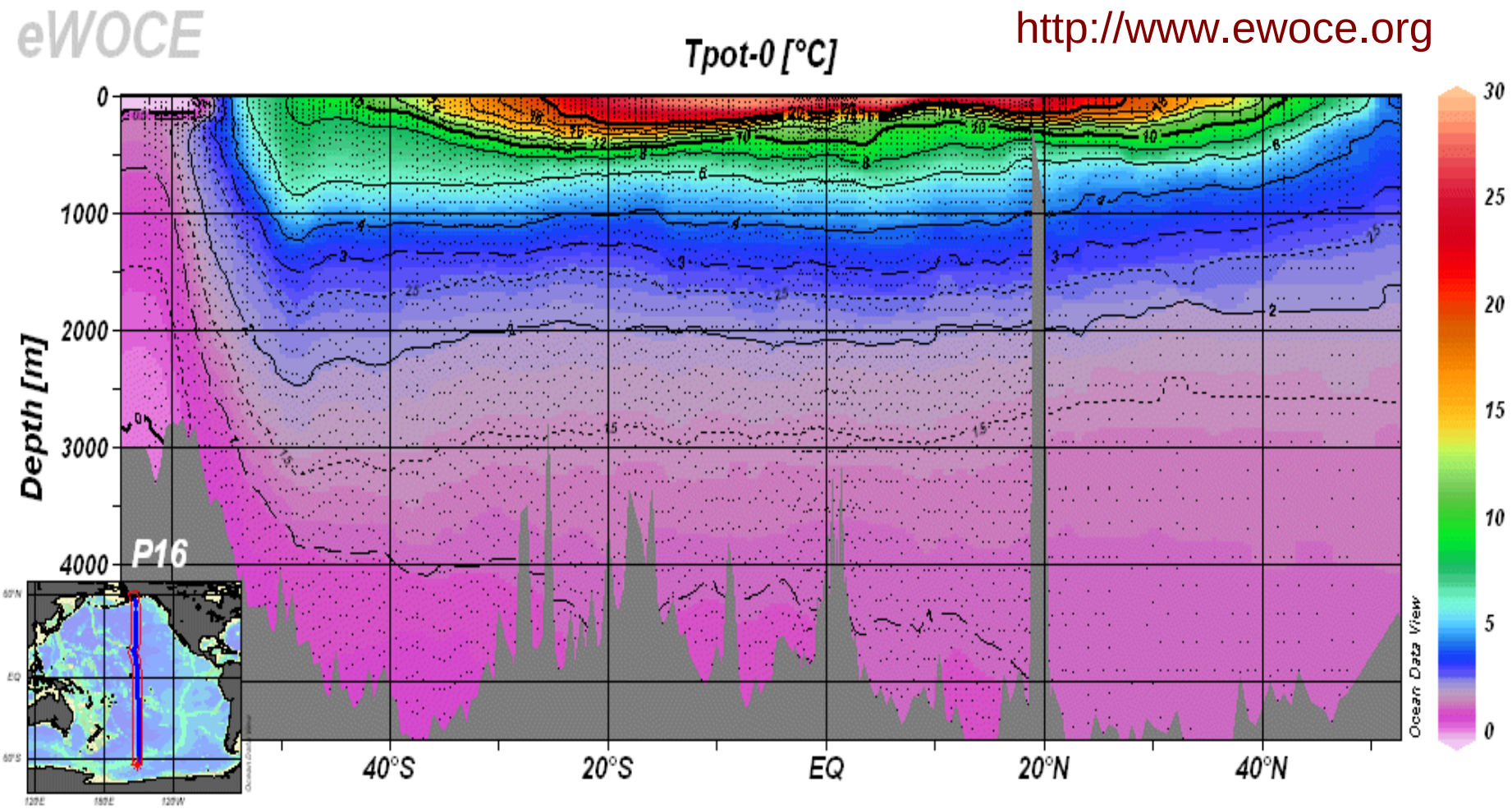
Outline

- Water-masses / THC in the Southern Ocean
- Climate change impacts?
  - Via wind-forced mechanisms
  - Via freshwater perturbations
- Tipping points for the Southern Ocean?
- Conclusions

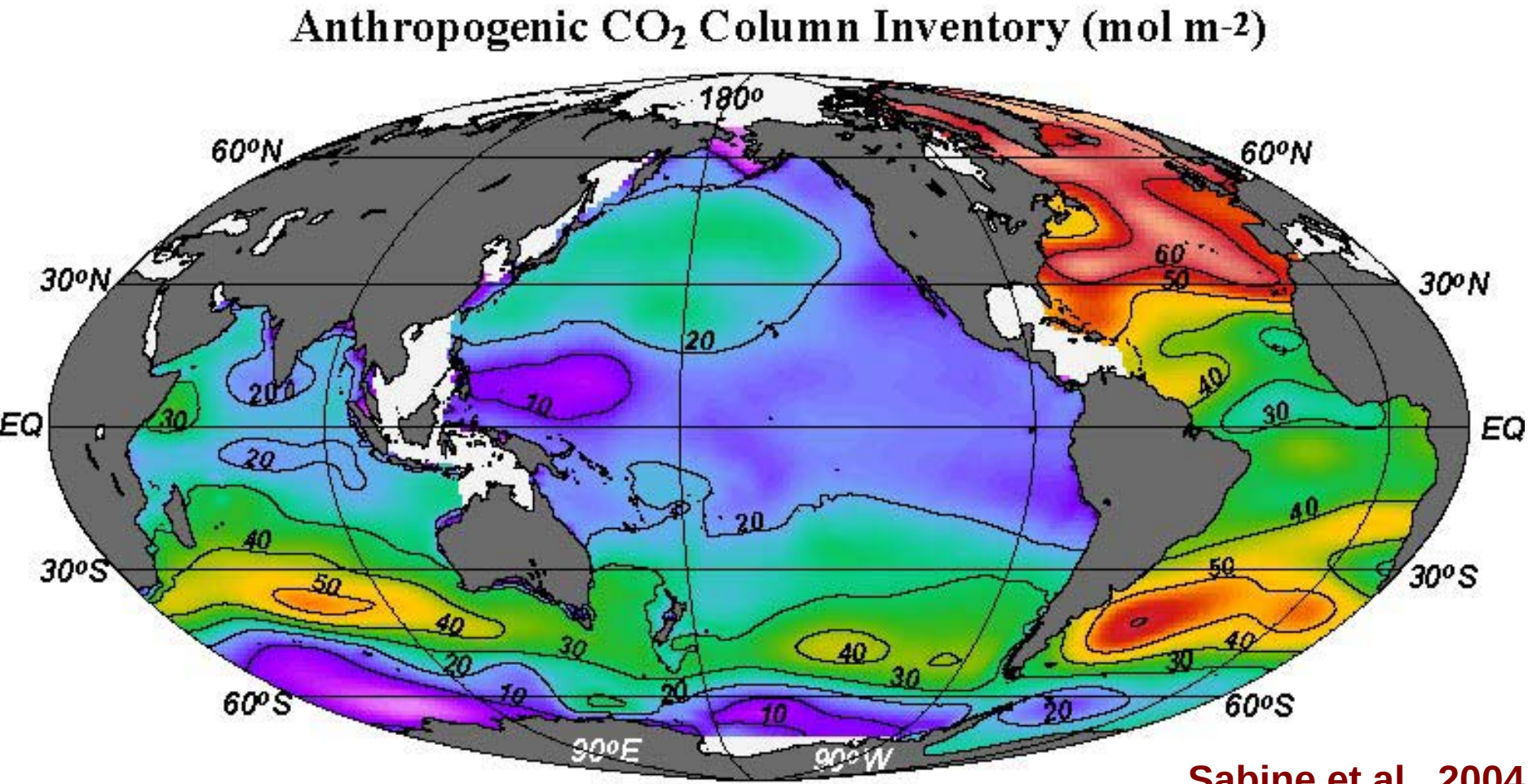
Southern Ocean water-masses



Antarctic water masses dominate the oceanic interior

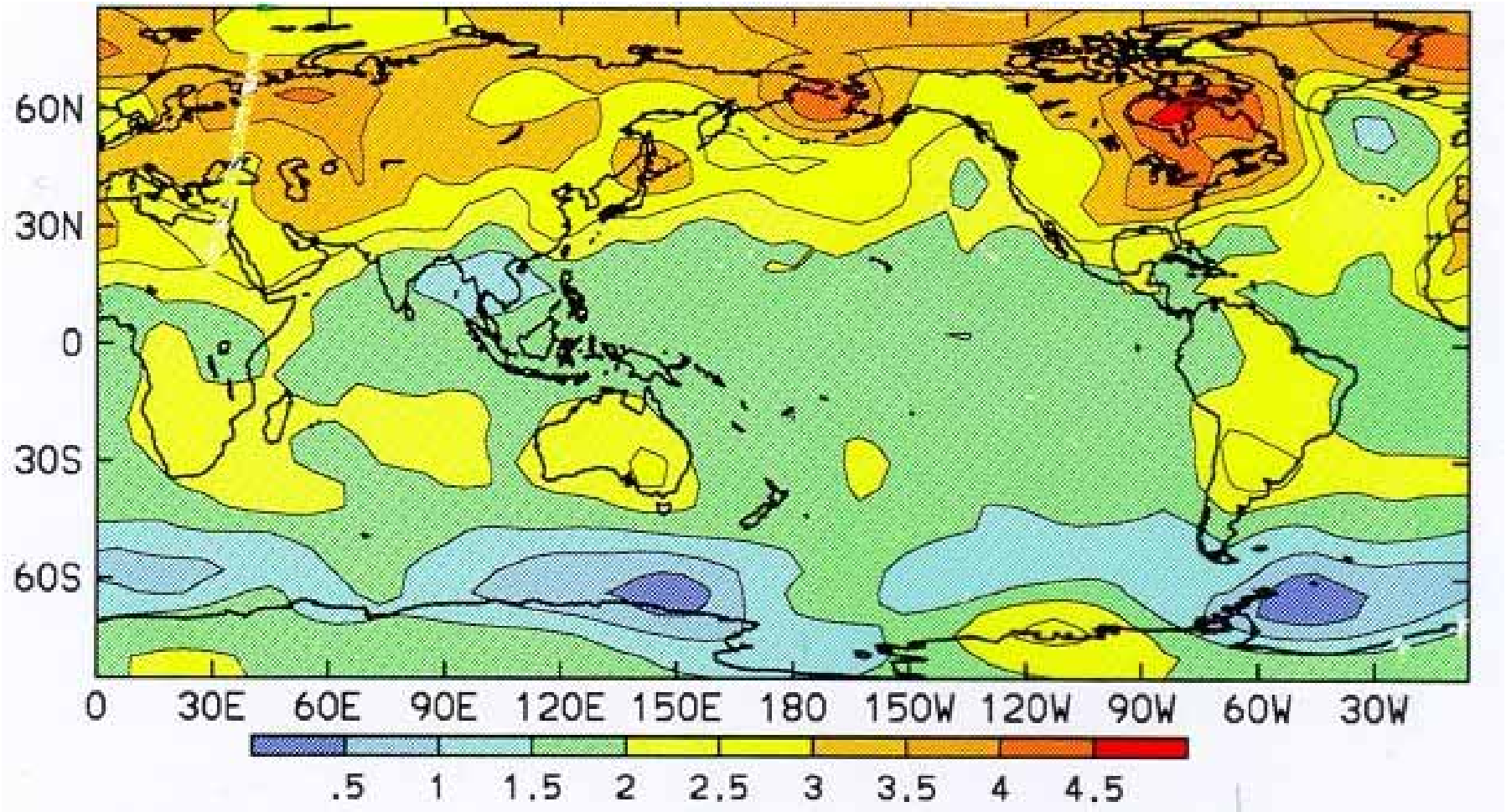


The Southern Ocean is a major sink of atmospheric CO_2



Sabine et al., 2004

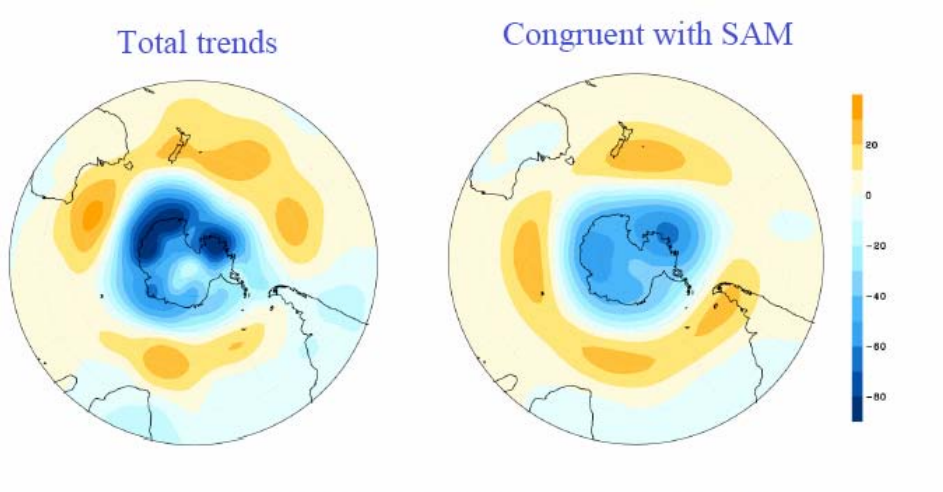
Climate change appears to be buffered by the Southern Ocean THC



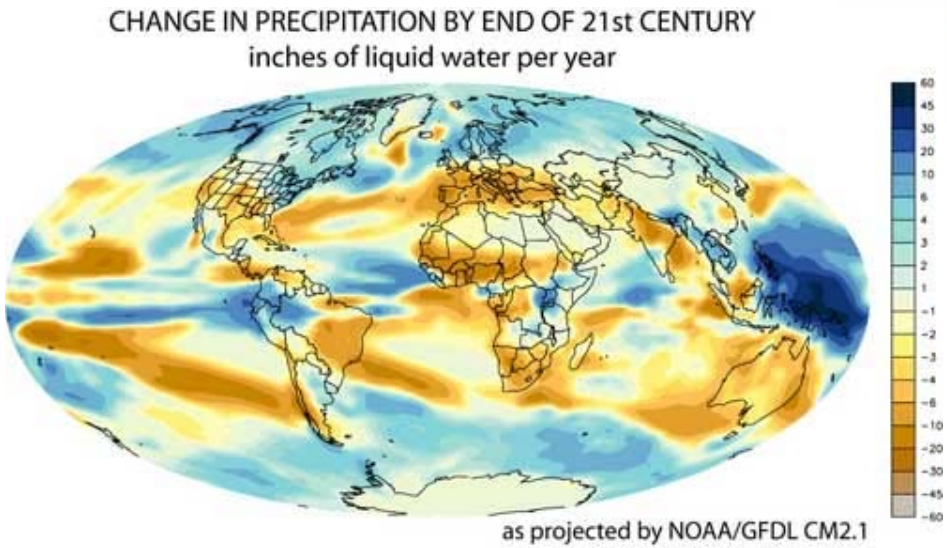
Annual-mean temperature change predicted for ~ the year 2050 in the GFDL coupled climate model experiment (Manabe et al. 1989).

We know that surface fluxes are changing over the Southern Ocean

… heat, FW, wind stress,…



Recent trends in SH Z500 (Dec.-May 1979-2000).



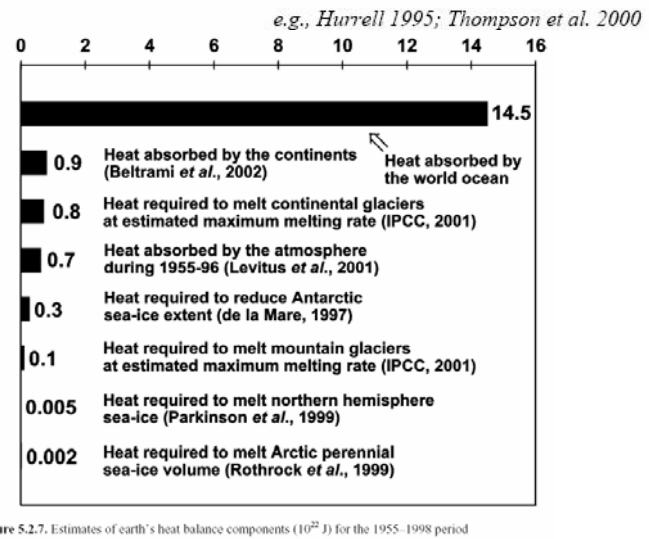


Figure 5.2.7. Estimates of earth's heat balance components (10^{22} J) for the 1955–1998 period

Modes of interannual to multi-century water-mass variability in the Southern Ocean

Water mass	Dominant time-scale	Variability mechanism	Reference
SAMW	Interannual	Northward wind-driven Ekman transport	Rintoul and England [2002, JPO]
AAIW	3-5 year	Air-sea and ice-sea fluxes	Santoso and England [2004, JPO]
CDW	Centennial and beyond	Varying transport / properties of NADW	Santoso, Hirst & England [JPO, 2006]
AABW	Multi-decadal	Sea-ice variability	Santoso and England [JPO; 2008]

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AABW	Multi-decadal	Sea-ice variability	Santoso and England [JPO; 2008]

Observations of temperature at intermediate depths show a warming at high latitudes and a cooling at mid-latitudes of the Southern Ocean over the last 50 years (e.g. Bindoff and Church, 1994; Gille 2002, Wong et al., 1999 …).

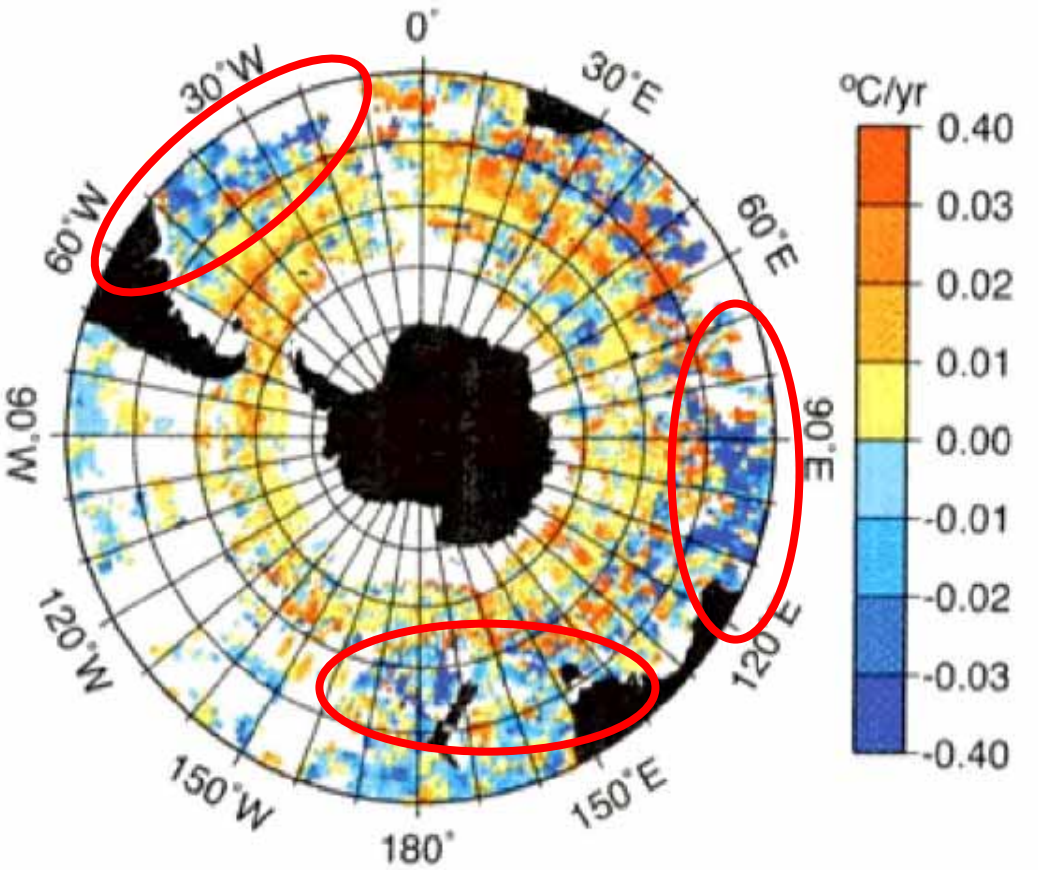


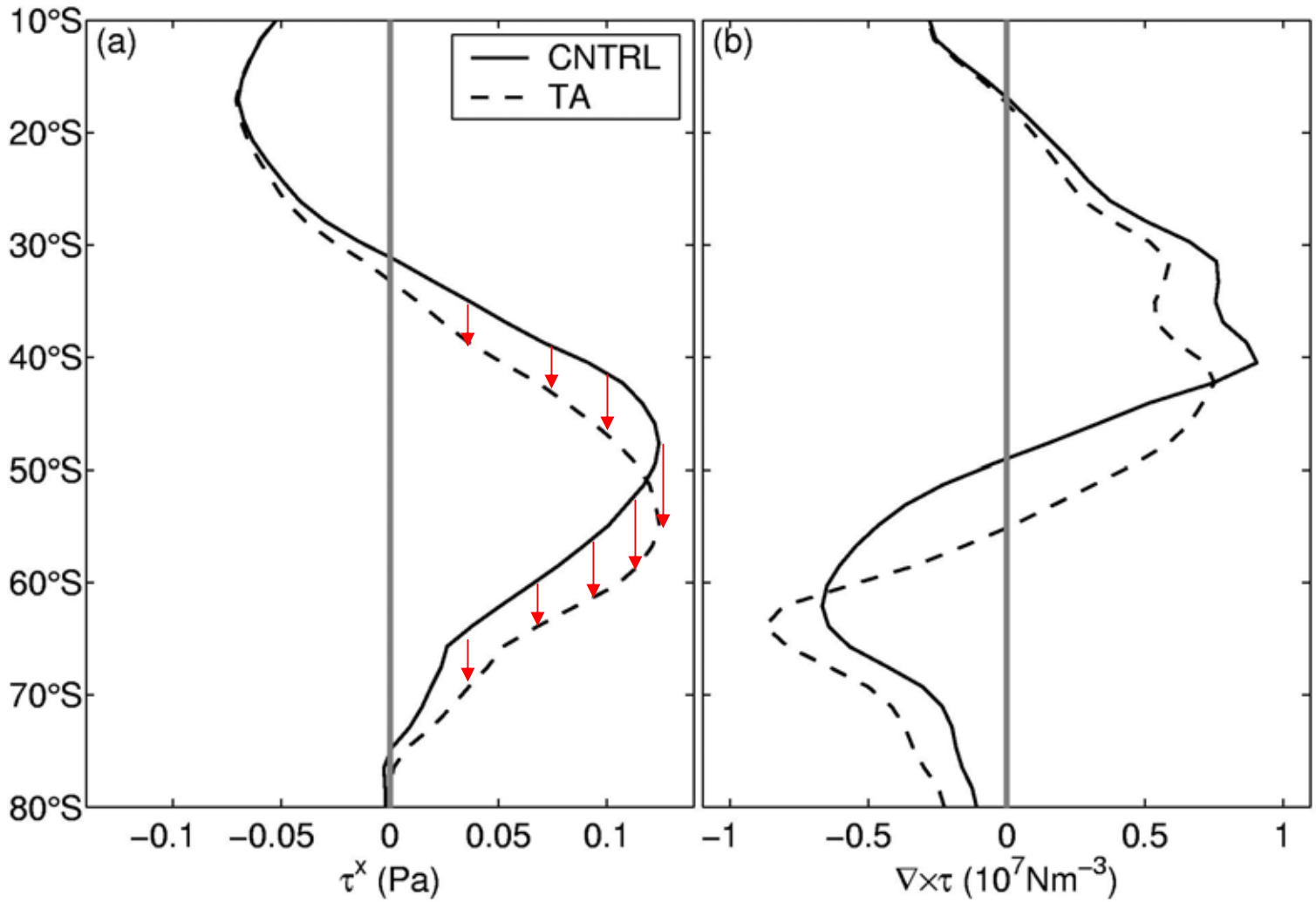
Figure 3 from Gille, S. T., 2002. Warming of the Southern Ocean since the 1950s. *Science*, **295**, 1275-1277.

Temperature trends between 700 and 1100 m depth from ALACE floats.

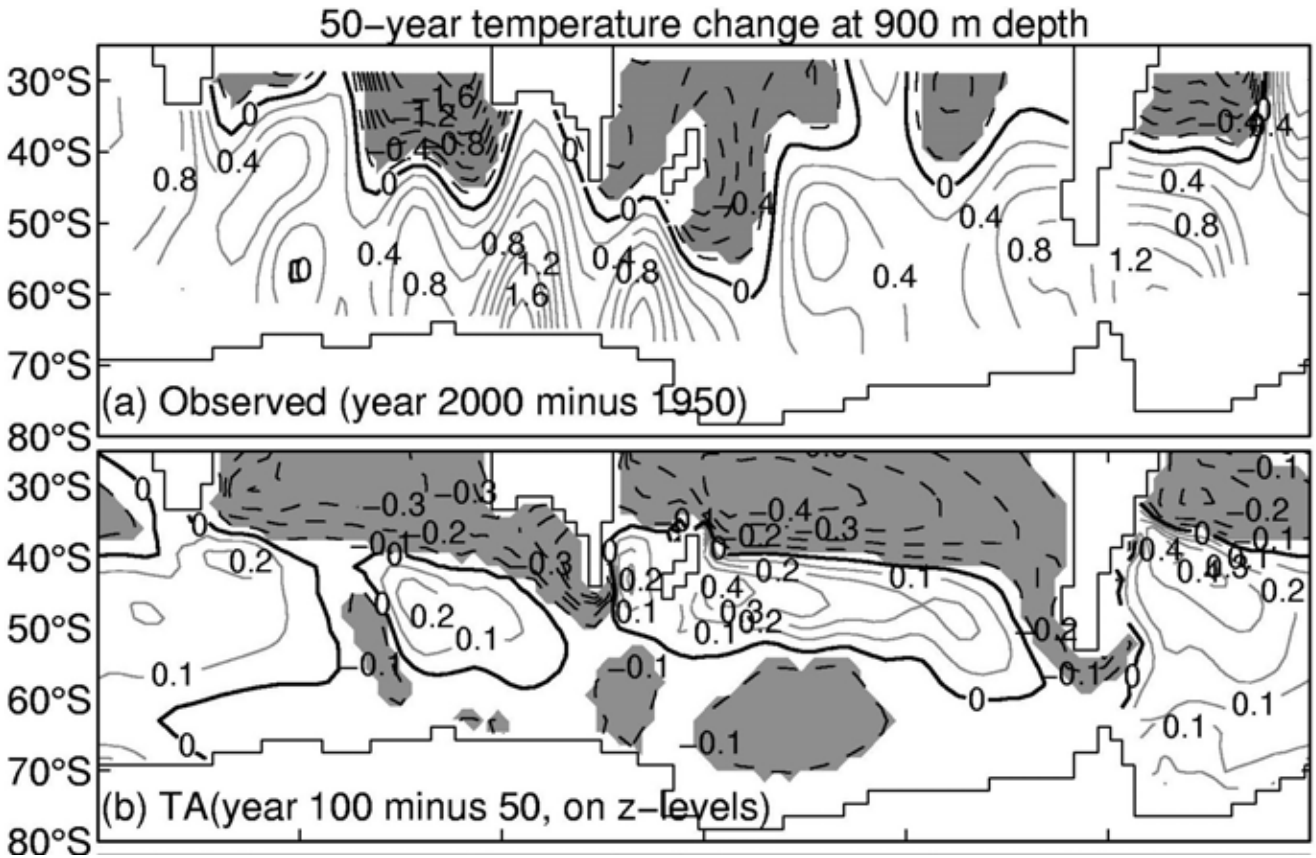
Role of the poleward shift in subpolar westerly winds?

Oke and England [2004, J Clim]

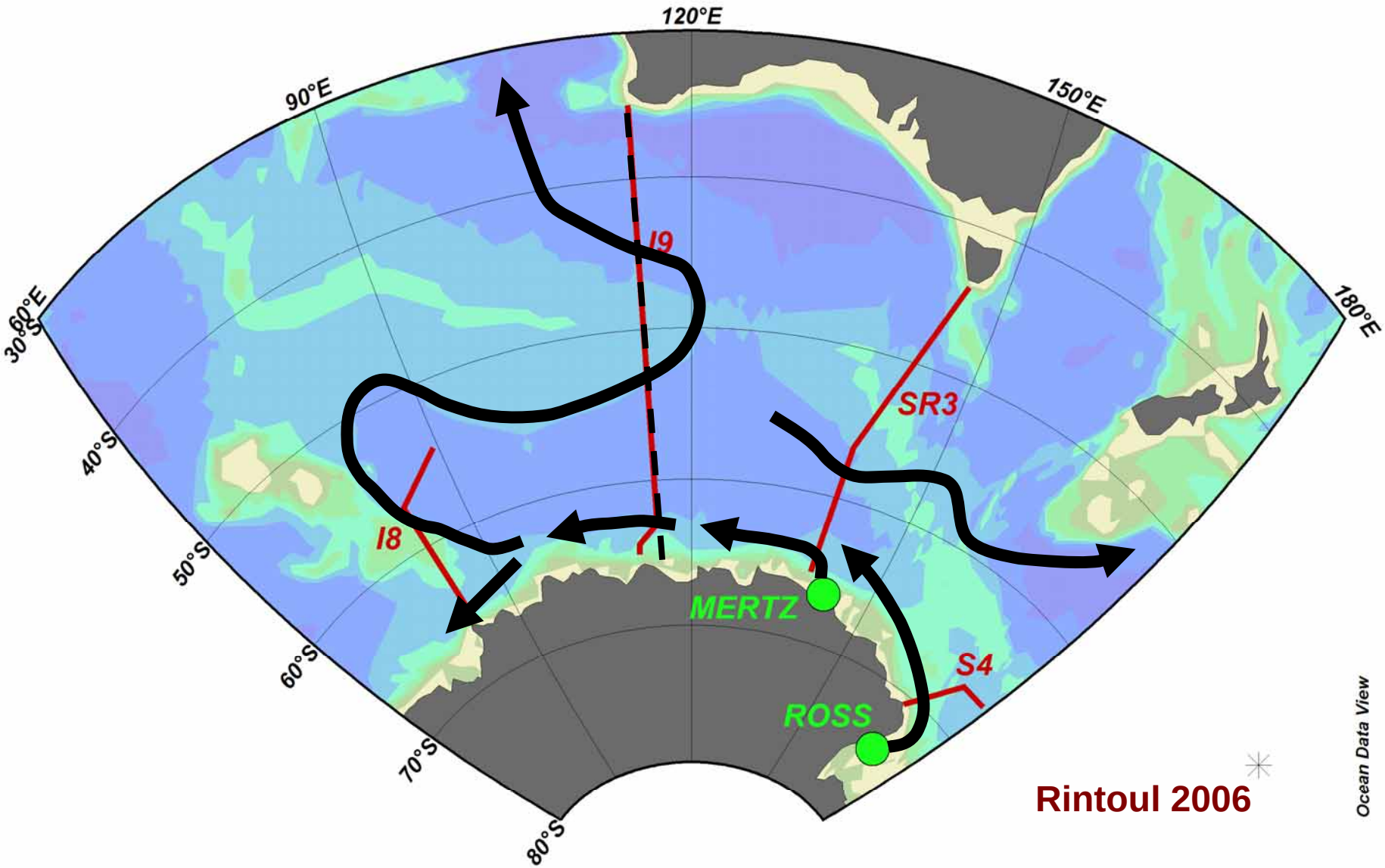
Zonal mean zonal wind stress:

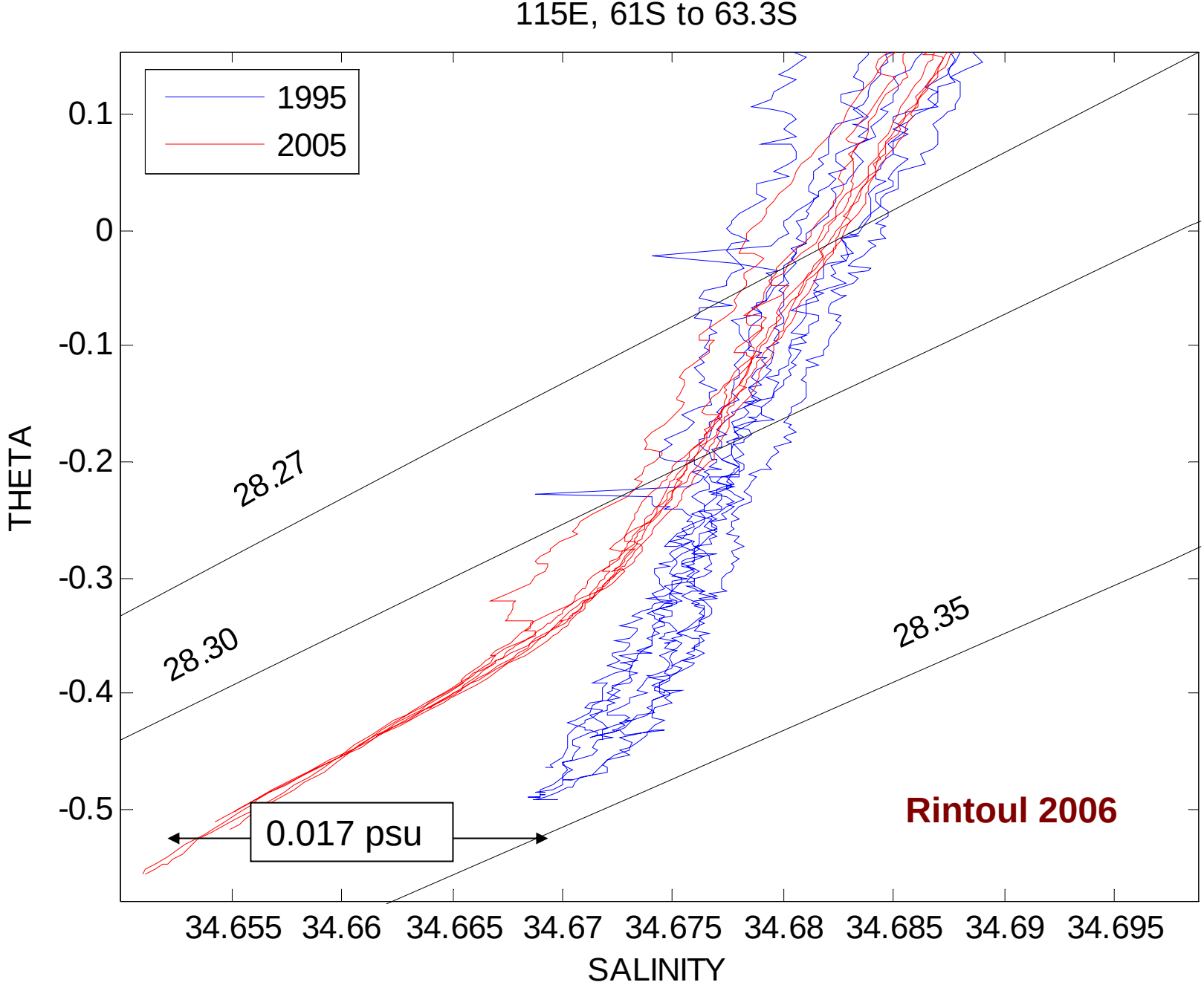


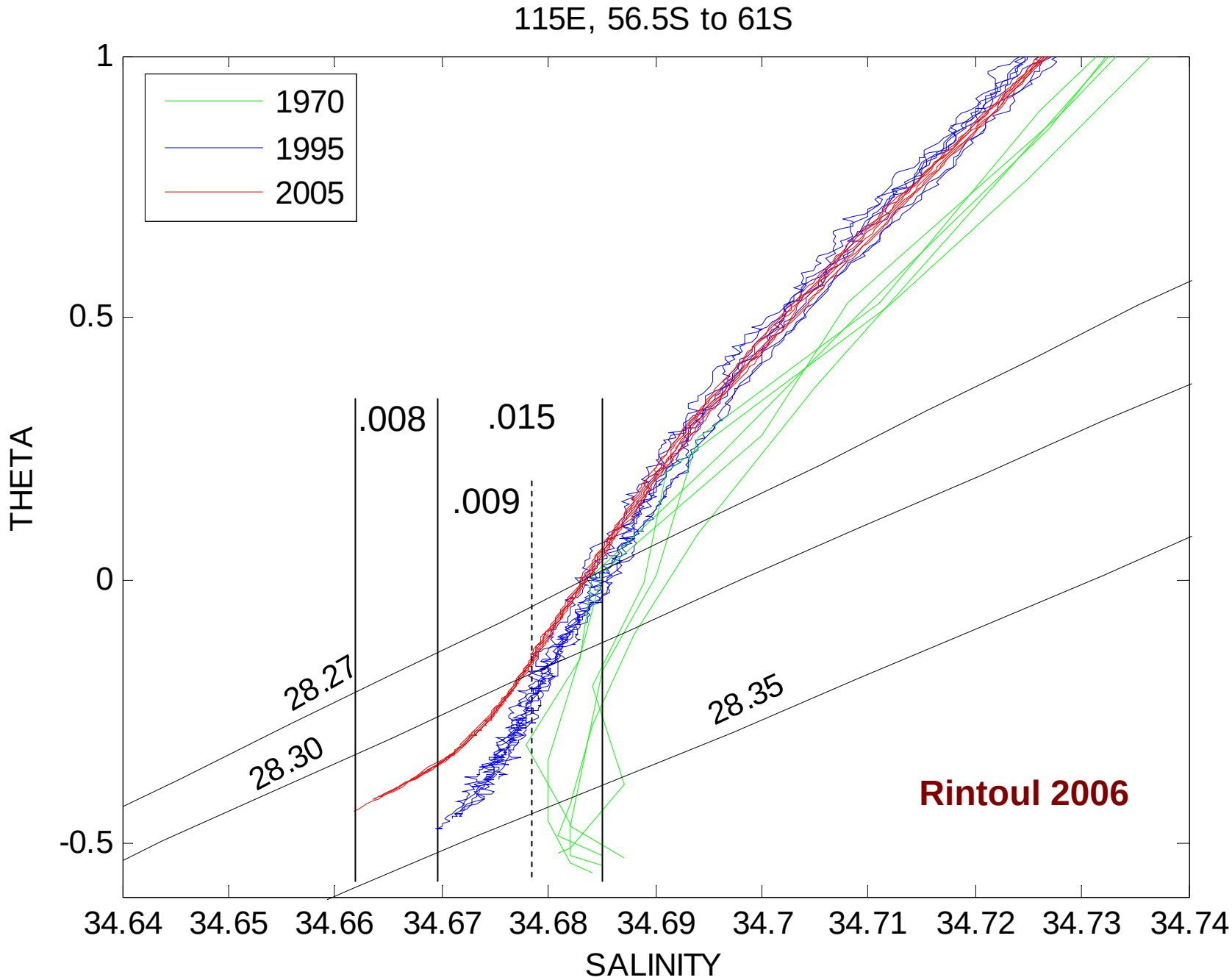
Implications for the observed cooling at intermediate depths



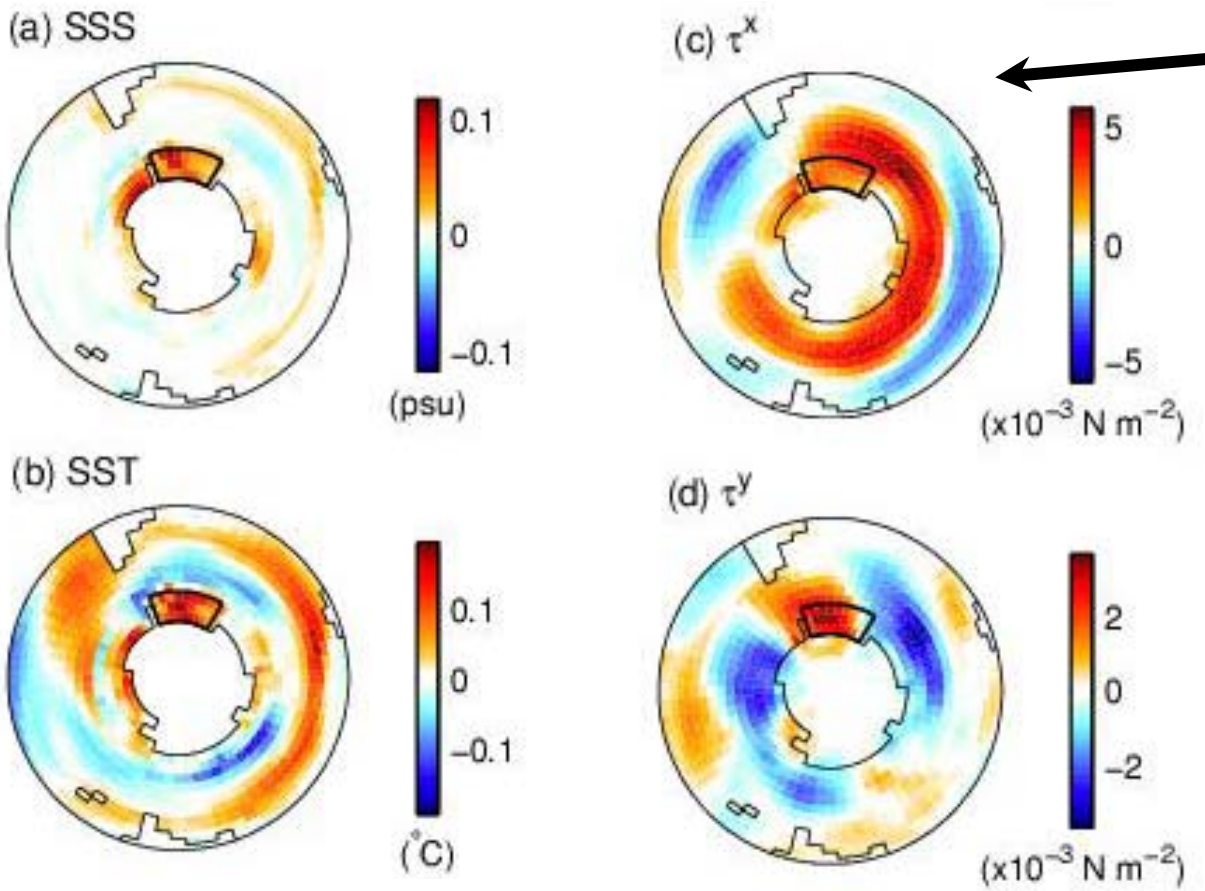
Oke and England [2004, J Clim]


120°E
90°E
150°E
180°E
60°E
30°S
40°S
50°S
60°S
70°S
80°S
I9
I8
SR3
MERTZ
S4
ROSS
Rintoul 2006
Ocean Data View


115E, 61S to 63.3S
1995
2005
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
THETA
28.27
28.30
28.35
0.017 psu
Rintoul 2006
34.655
34.66
34.665
34.67
34.675
34.68
34.685
34.69
34.695
SALINITY


115E, 56.5S to 61S
1970
1995
2005
1
0.5
0
-0.5
THETA
.008
.015
.009
28.27
28.30
28.35
Rintoul 2006
34.64
34.65
34.66
34.67
34.68
34.69
34.7
34.71
34.72
34.73
34.74
SALINITY

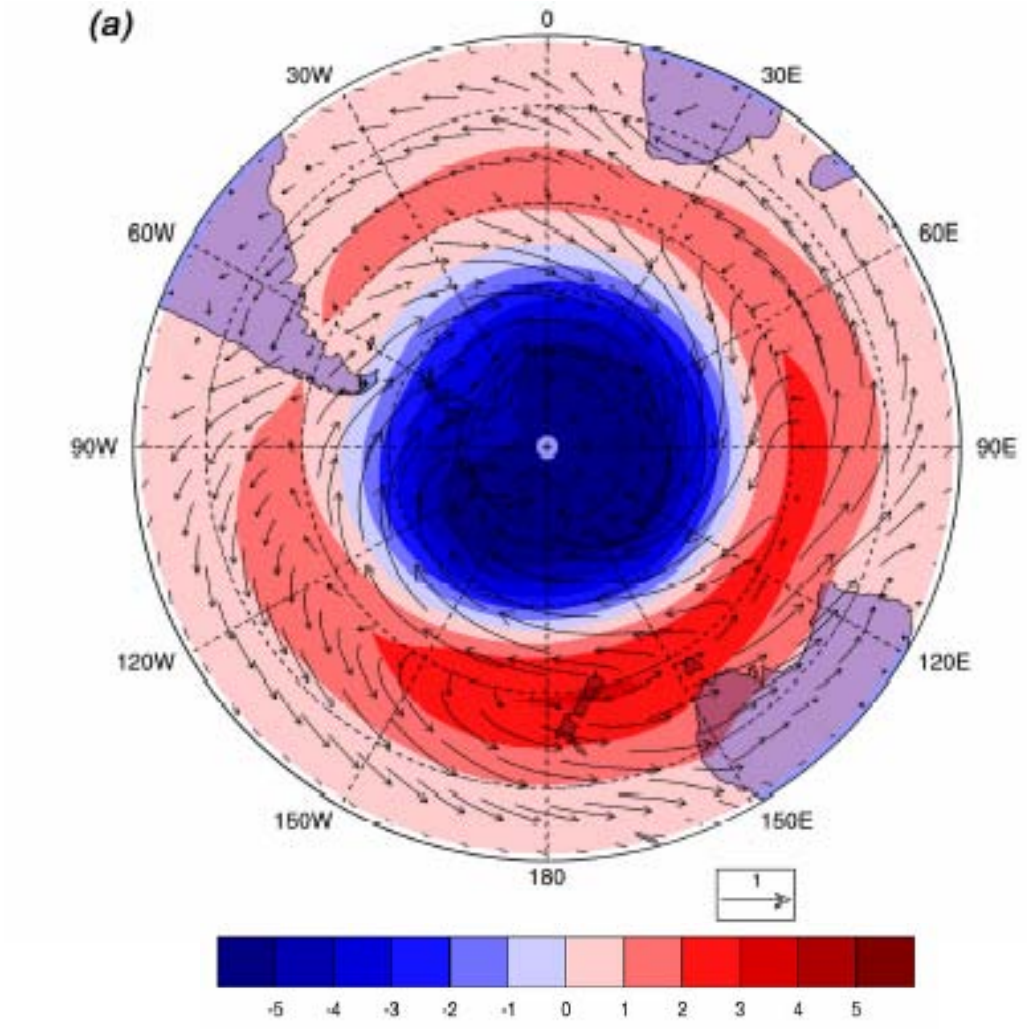
Composite properties during years of high salinity WSSW

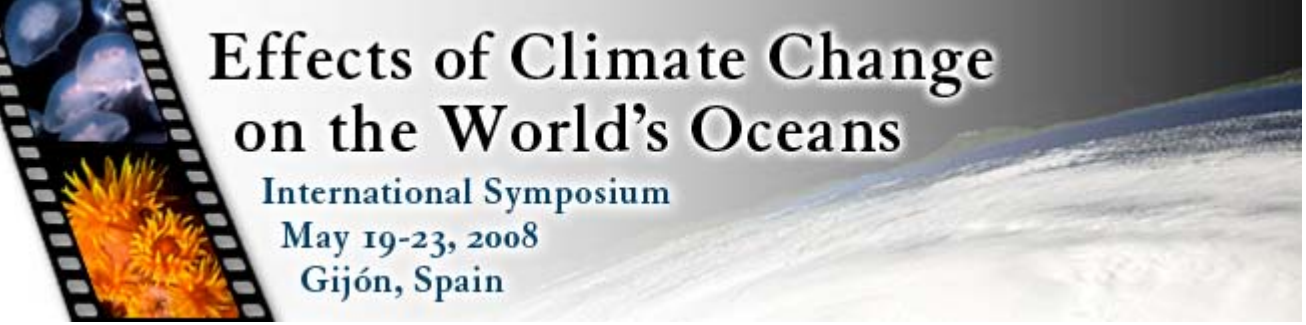


An imprint of the Southern Annular Mode

Santoso and England (2008) JPO, in press

Link from SH climate modes to Southern Ocean water masses?



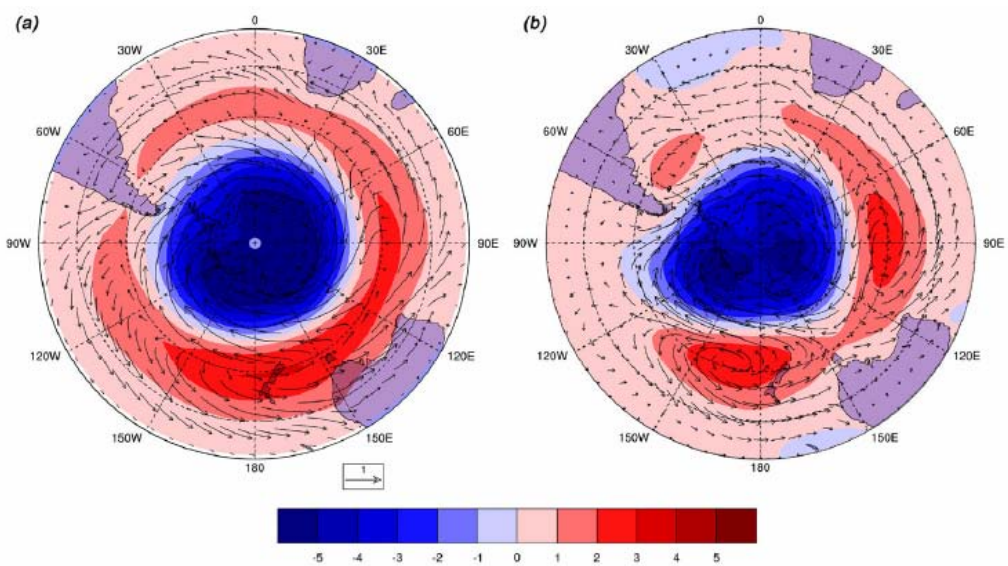


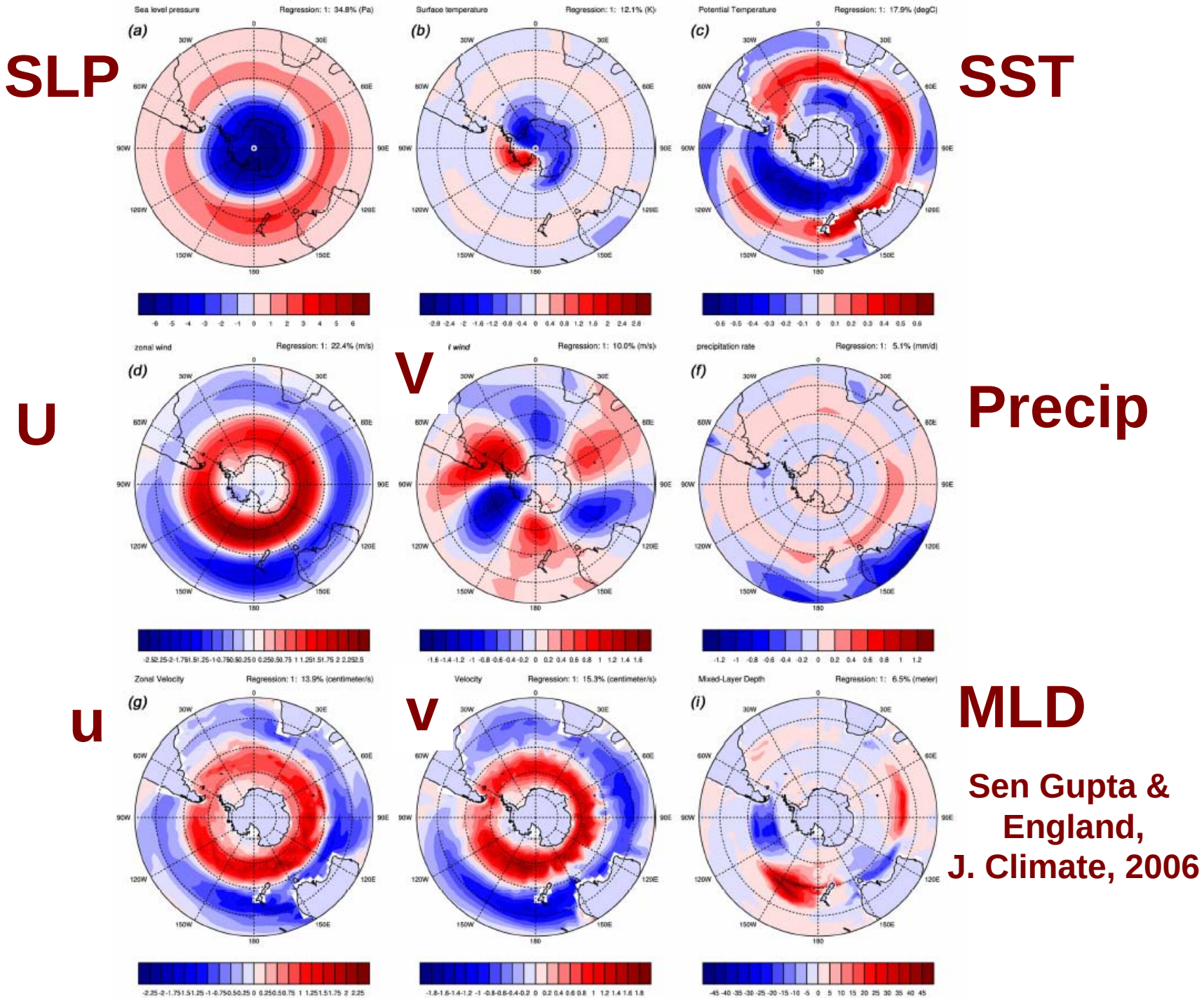
Coupled Ocean–Atmosphere–Ice Response to Variations in the Southern Annular Mode

ALEXANDER SEN GUPTA AND MATTHEW H. ENGLAND

Centre for Environmental Modelling and Prediction, School of Mathematics, University of New South Wales, Sydney, New South Wales, Australia

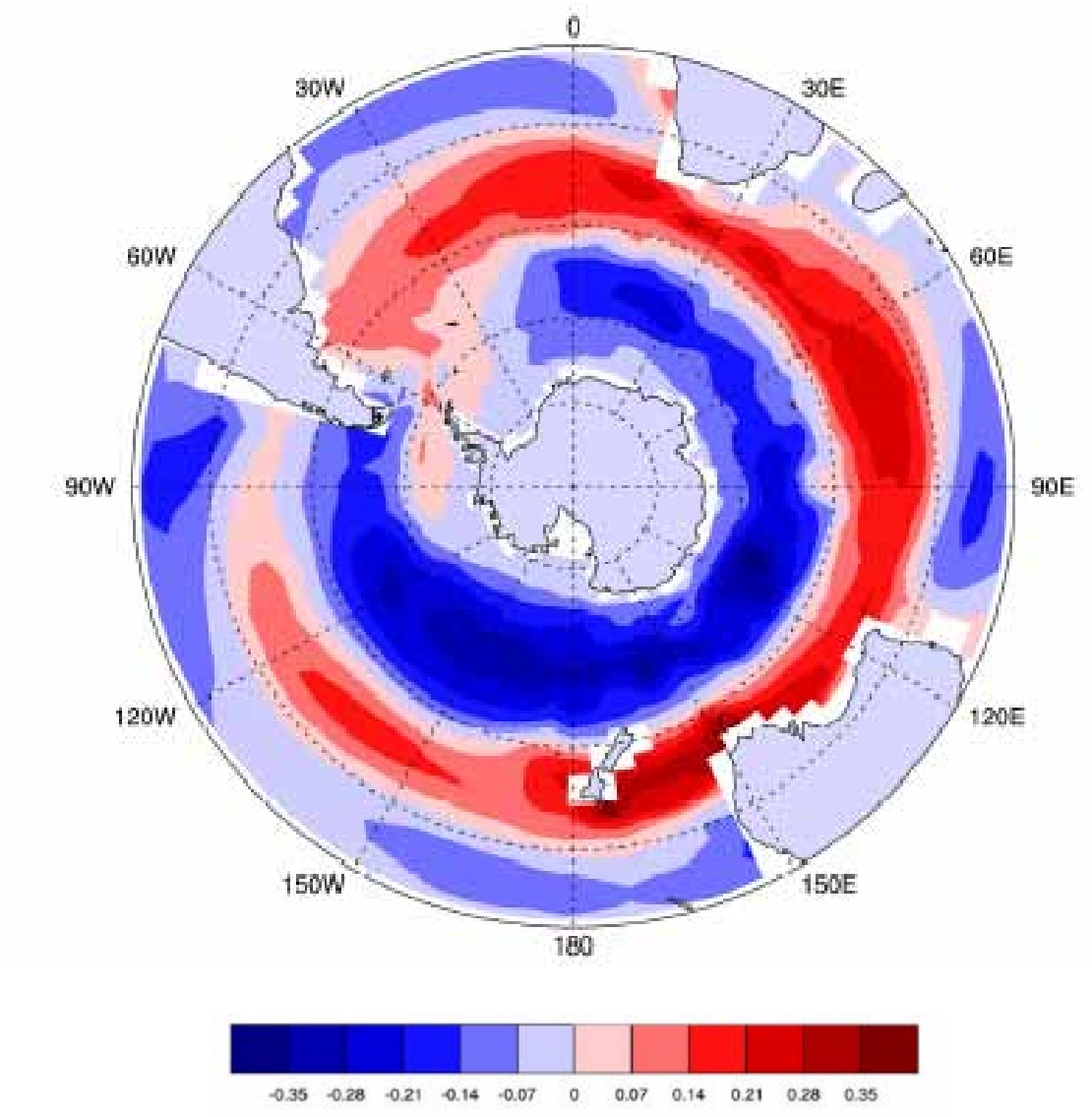
J. Climate (2006)

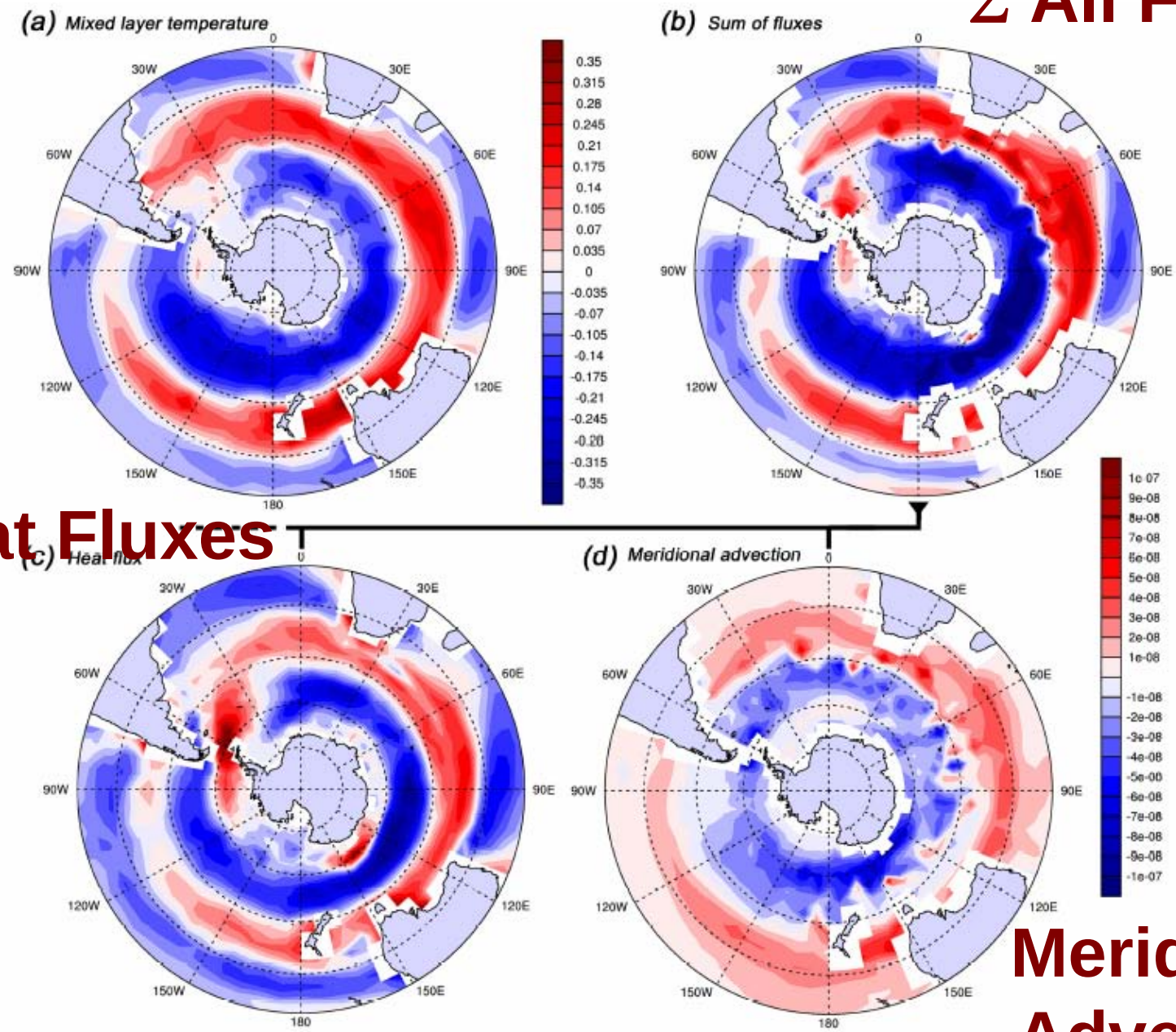




Sen Gupta & England, J. Climate, 2006

Regression of the Southern Annular Mode onto sea surface temperature





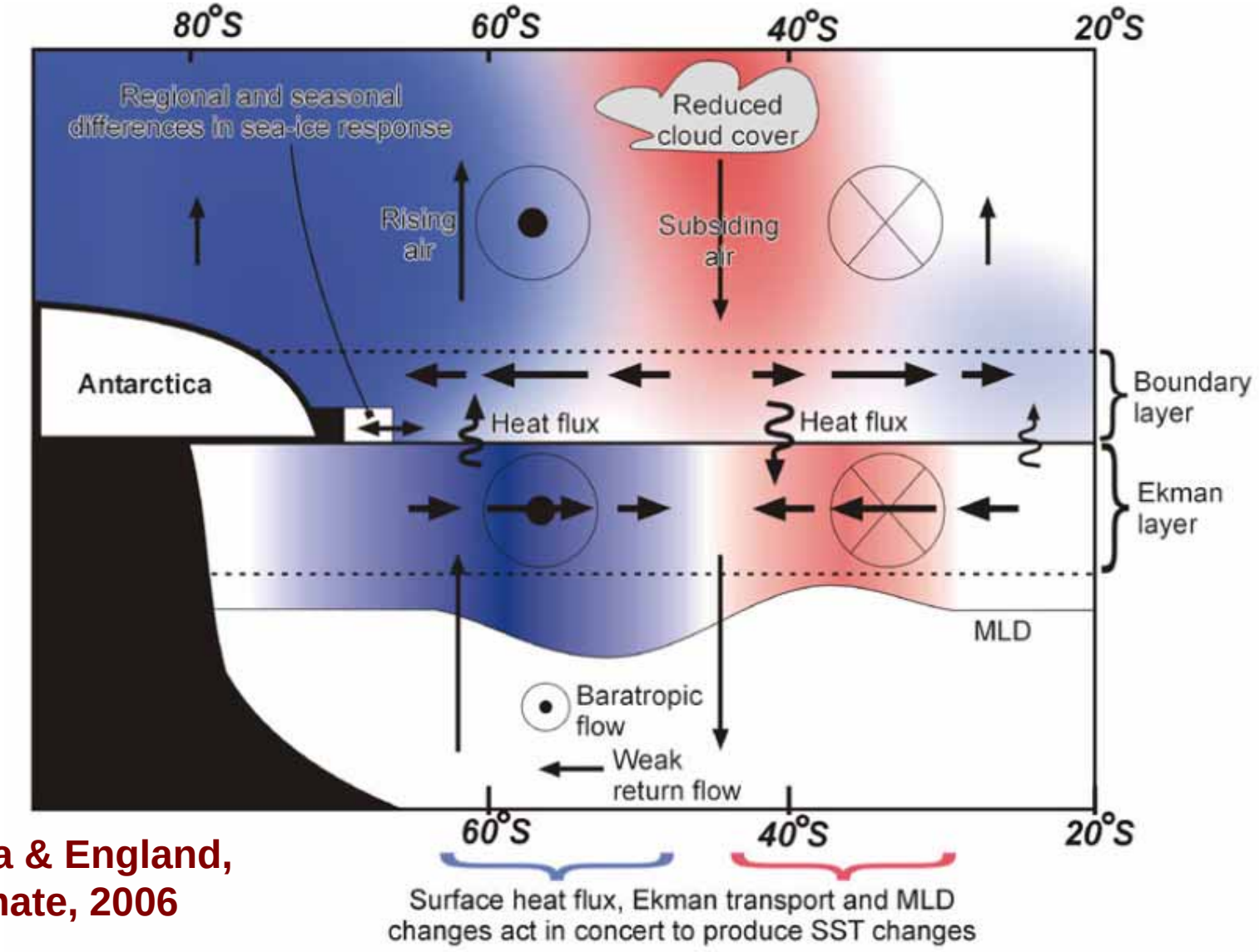
SST

Σ All Fluxes

Σ Heat Fluxes

Meridional Advection

Southern Annular Mode



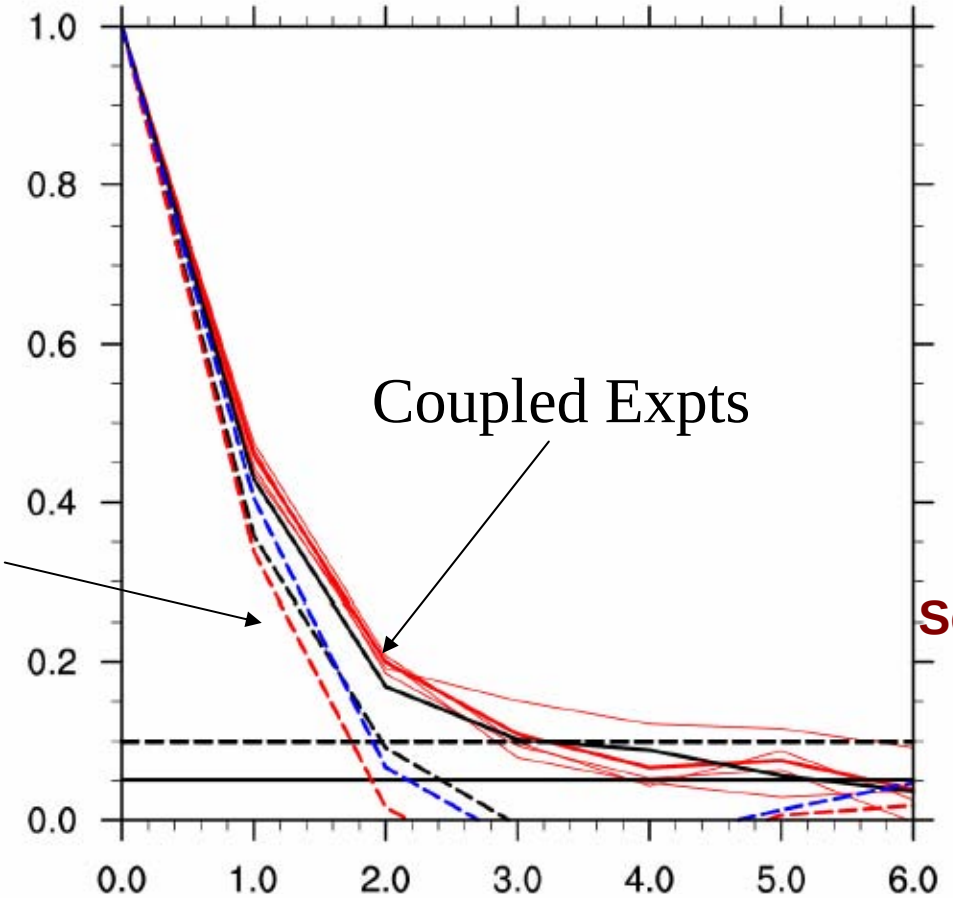
Sen Gupta & England, J. Climate, 2006

So….

- The Southern Annular Mode forces an **annular response** in ocean circulation and SST
- The SST response is **significant** due to a conspiring of ocean circulation (dynamic) and air-sea heat fluxes (thermodynamic)
- This favours **enhanced meridional SST gradients** that should act to re-enforce the intensification of the SWW’s

DOES THE OCEAN MATTER FOR THE SAM??

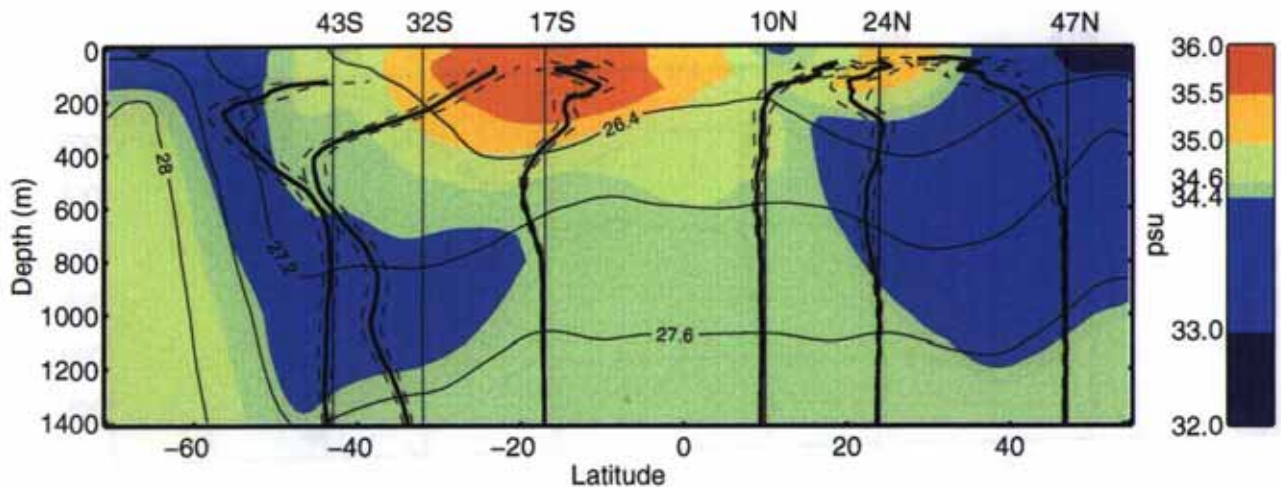
Autocorrelation of the SAM index in model experiments



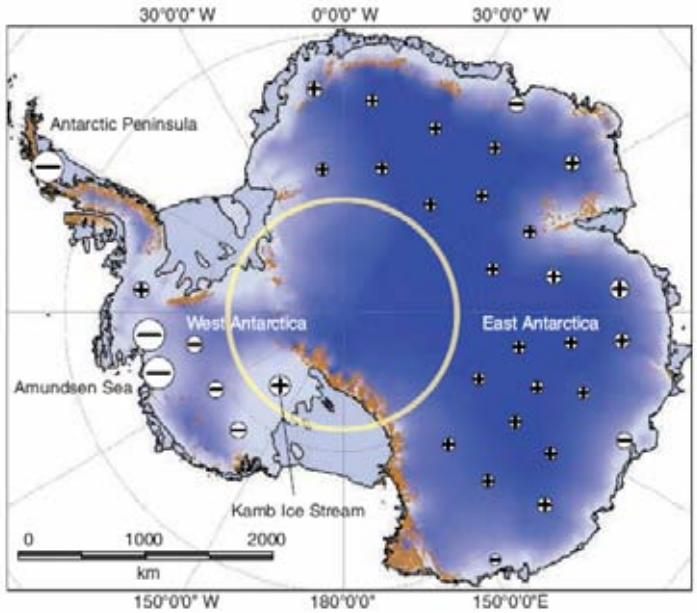
Sen Gupta & England, J. Climate, 2007

Fig. 3. Autocorrelation of SAM index for fully coupled integrations: ***PD*** (continuous thick red) and ***PI*** (continuous black) and prescribed ocean/ice integrations: ***AL_obs, AL_climo and A_climo*** (dotted lines). Thin red lines represent ***PD1-4 experiments***. 95% confidence intervals are also shown (horizontal lines – lower line for coupled 200yr experiments). (sam_index.ncl)

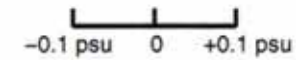
Impacts of freshwater flux changes?

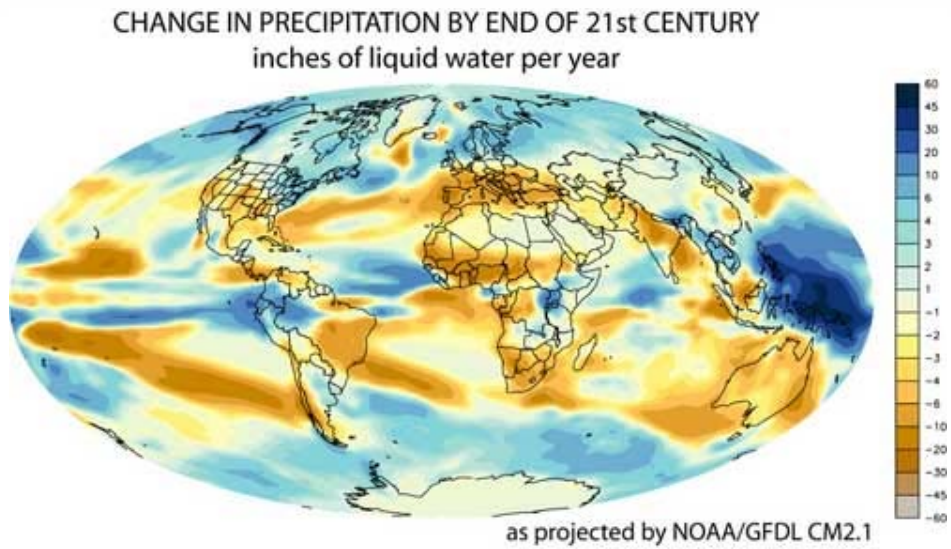


Davis et al., Vaughan; Science, 2005

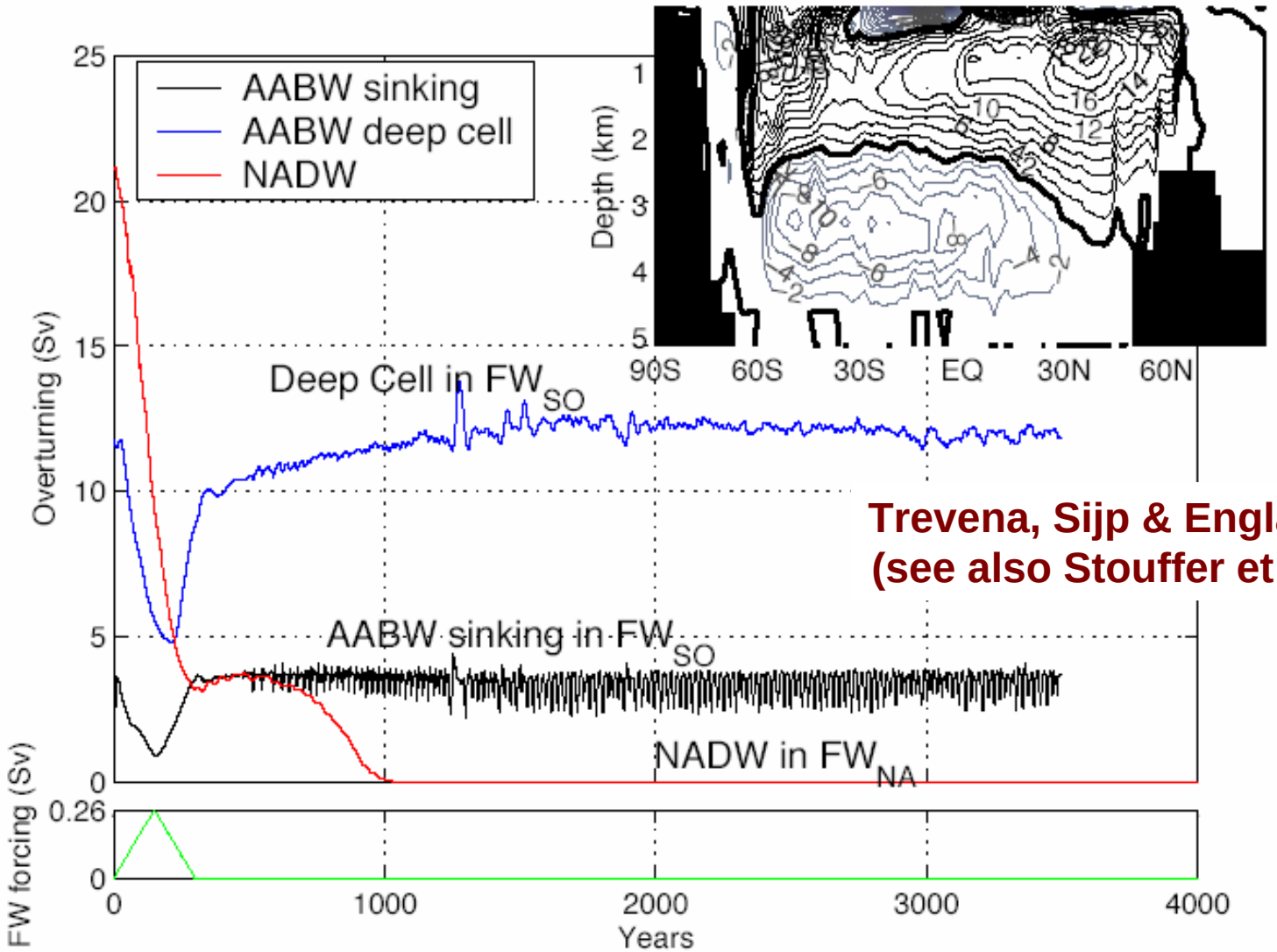


Wong et al., 1999

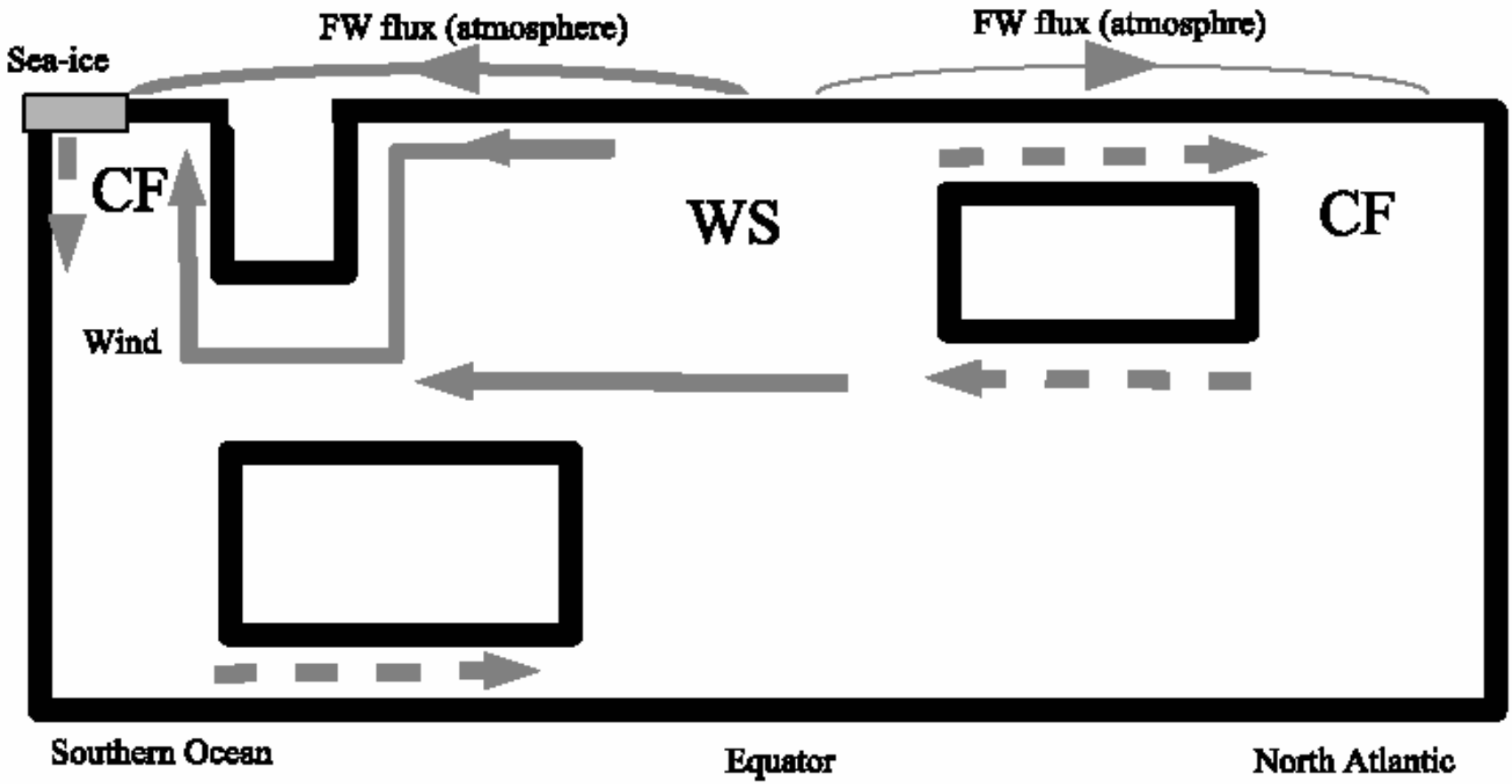




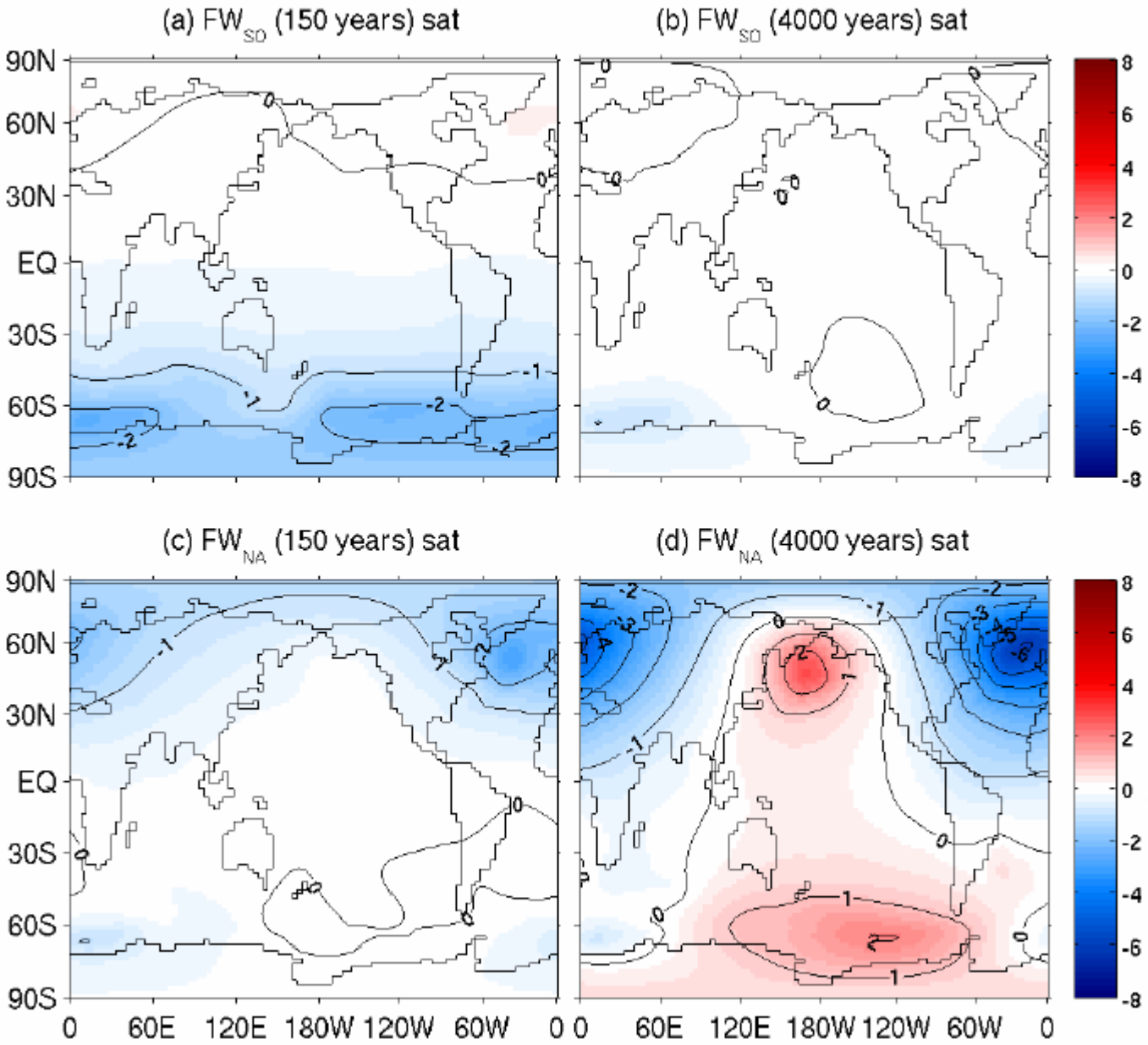
Does the Southern Ocean THC exhibit multiple steady states?



Trevena, Sijp & England, 2008 (see also Stouffer et al., 2007)

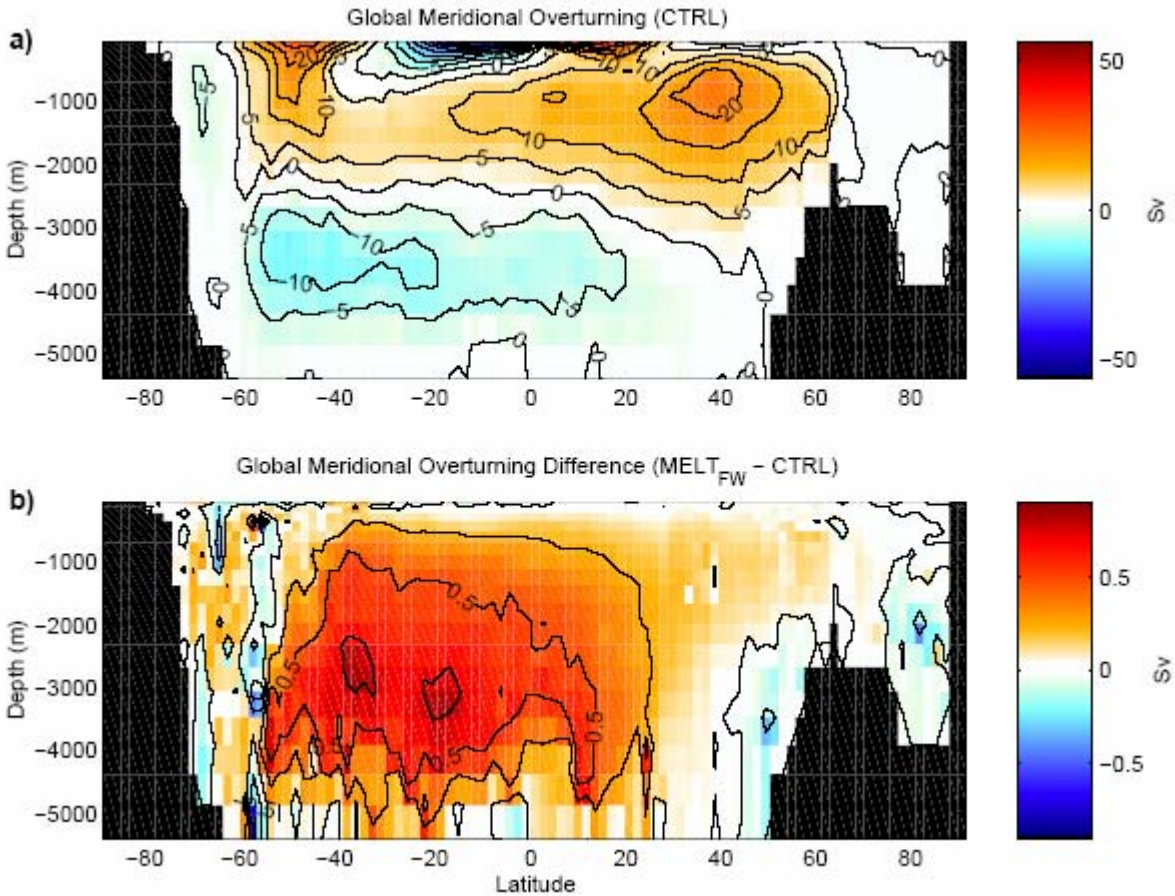


Trevena, Sijp & England, 2008



Trevena, Sijp & England, 2008

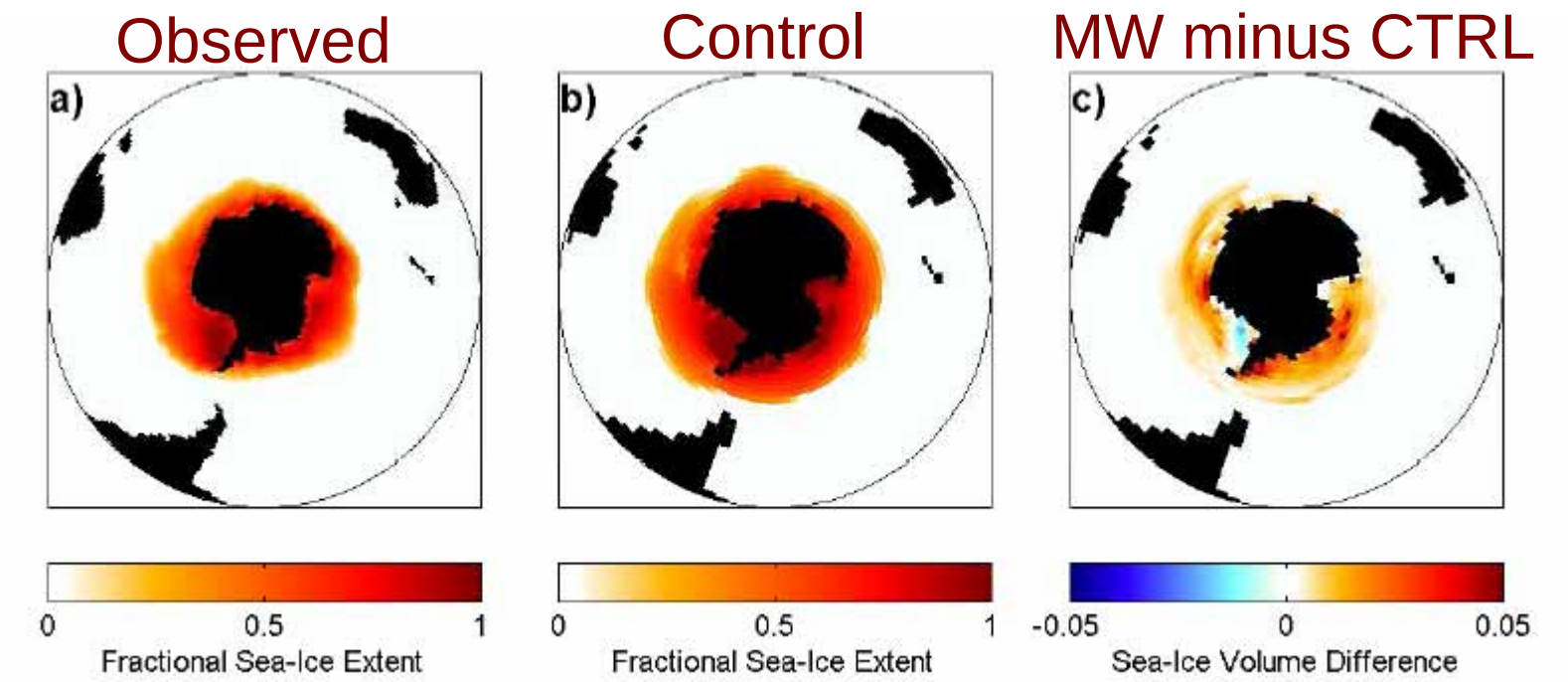
Southern Ocean THC response to sea-ice melt



Aiken and England (2008)

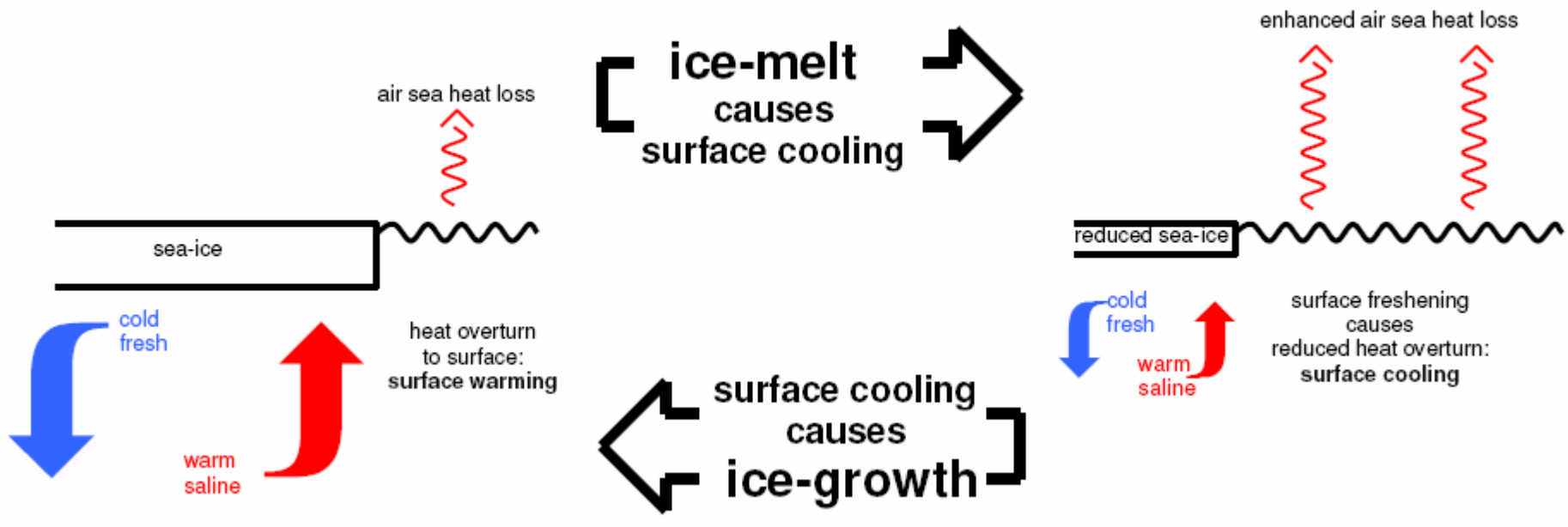
… consistent with findings that Antarctic sea-ice is "difficult" to melt back in coupled climate models

(Richardson et al. 2005, Goosse and Fichefet, 2006, Aiken and England, 2008)



Aiken and England, 2008

Negative feedback loop stabilises the system:



Aiken and England, 2008

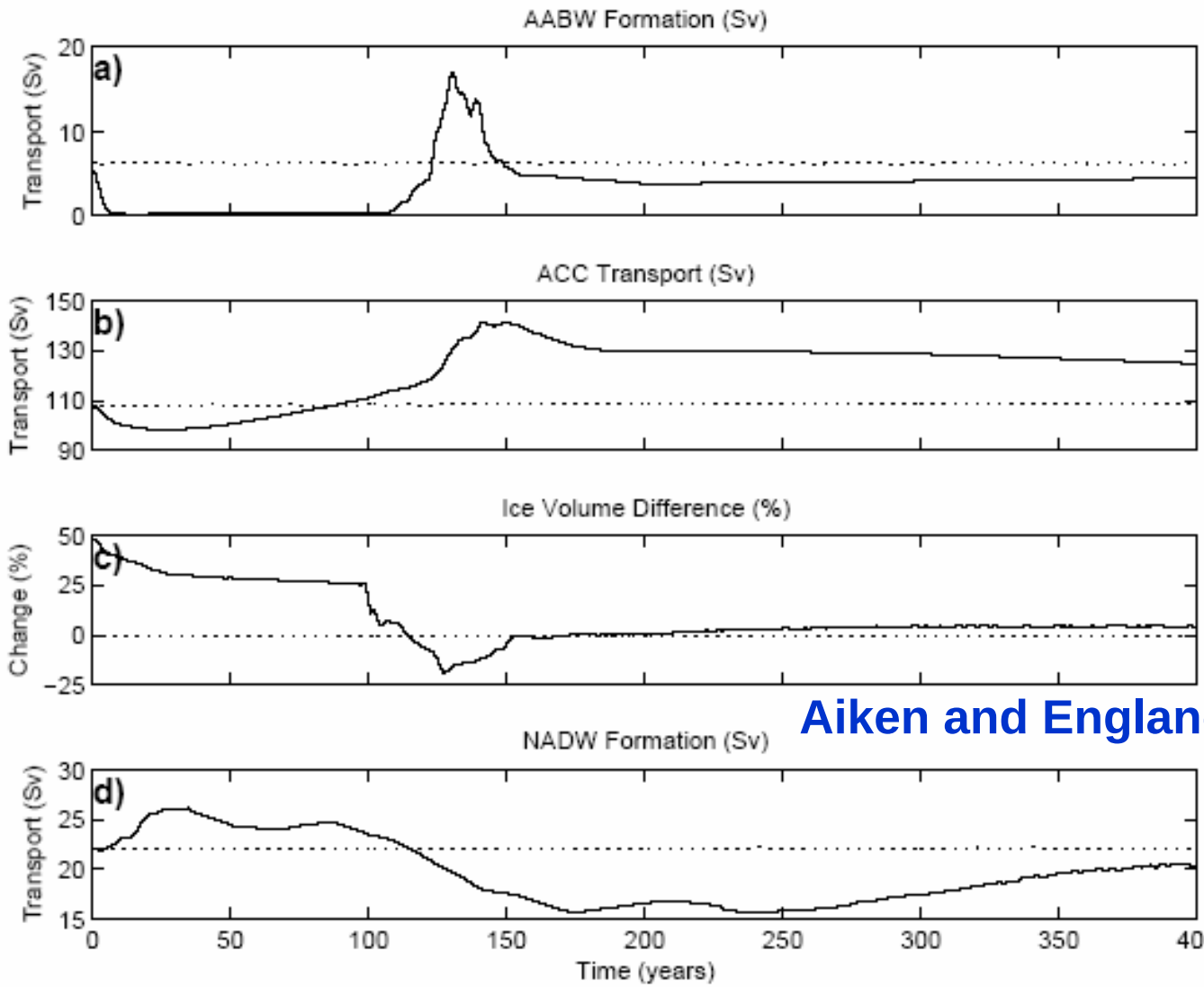
Southern Ocean THC response to land-ice melt

AABW

ACC

Sea-Ice

NADW



Aiken and England (2008)

Conclusions….

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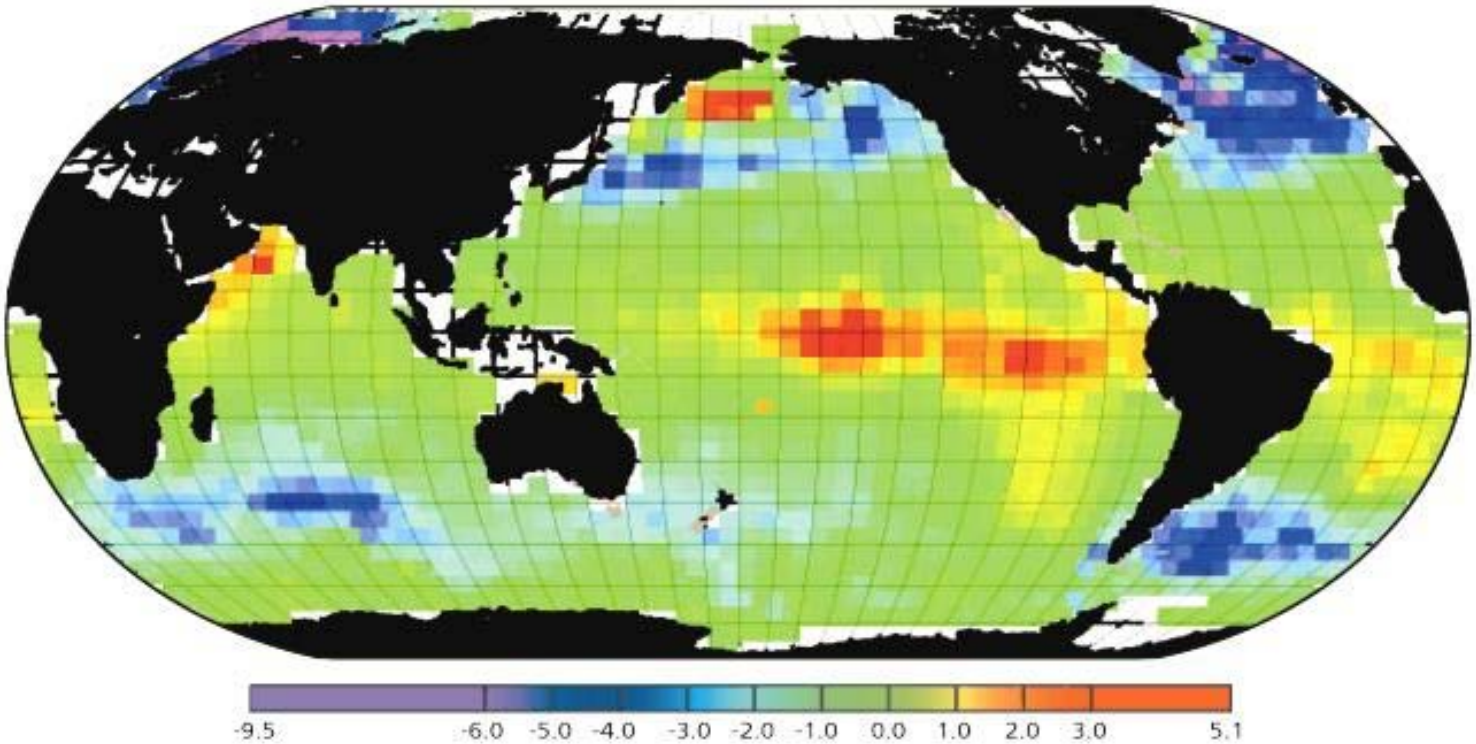
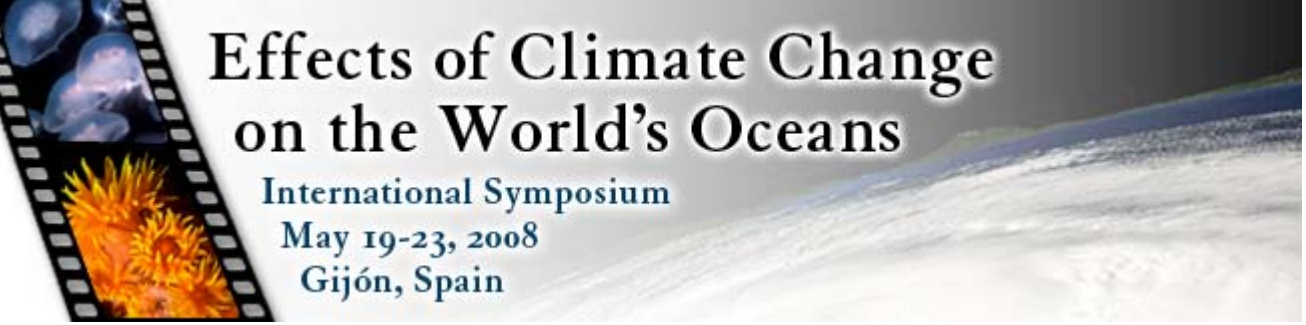
CO_2 Flux



Global map of the average annual exchange CO_2 flux (mol-C m^{-2} a^{-1}) across the sea surface. Reprinted from: Takahashi T. *et al.*, Net sea-air CO_2 flux over the global oceans, Proceedings 2nd International Symposium CO_2 in the Oceans. CGER-I037-'99, p. 9-15 © 1999 CGER/NIES/EAJ

JGOFS



surface flux

Southern Hemisphere ~~westerly wind~~ control over the ocean's thermohaline circulation

Southern

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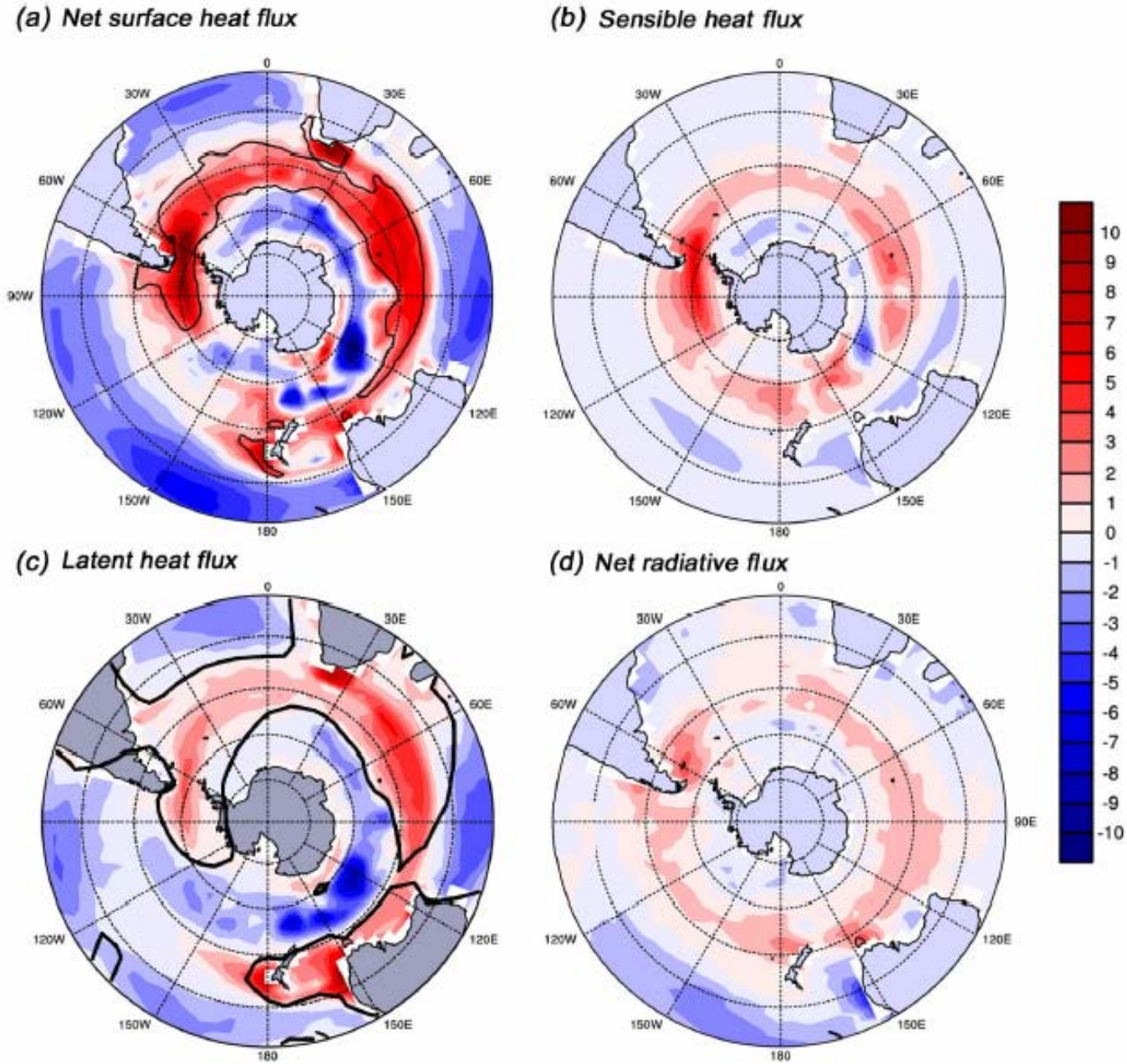
Climate Change Research Centre


(a) Net surface heat flux
(b) Sensible heat flux
(c) Latent heat flux
(d) Net radiative flux
0
30W
30E
60W
60E
90W
90E
120W
120E
150W
150E
180
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
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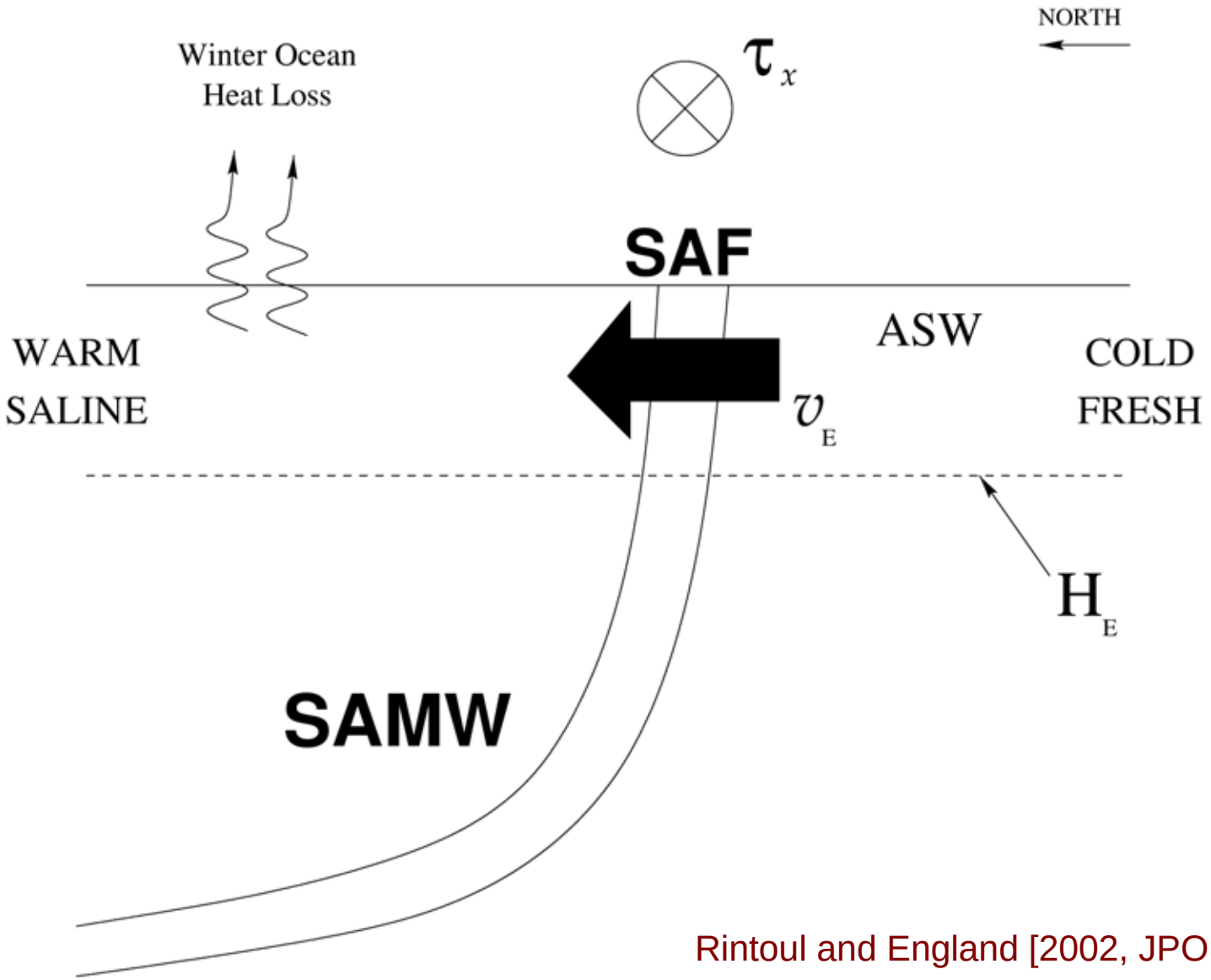
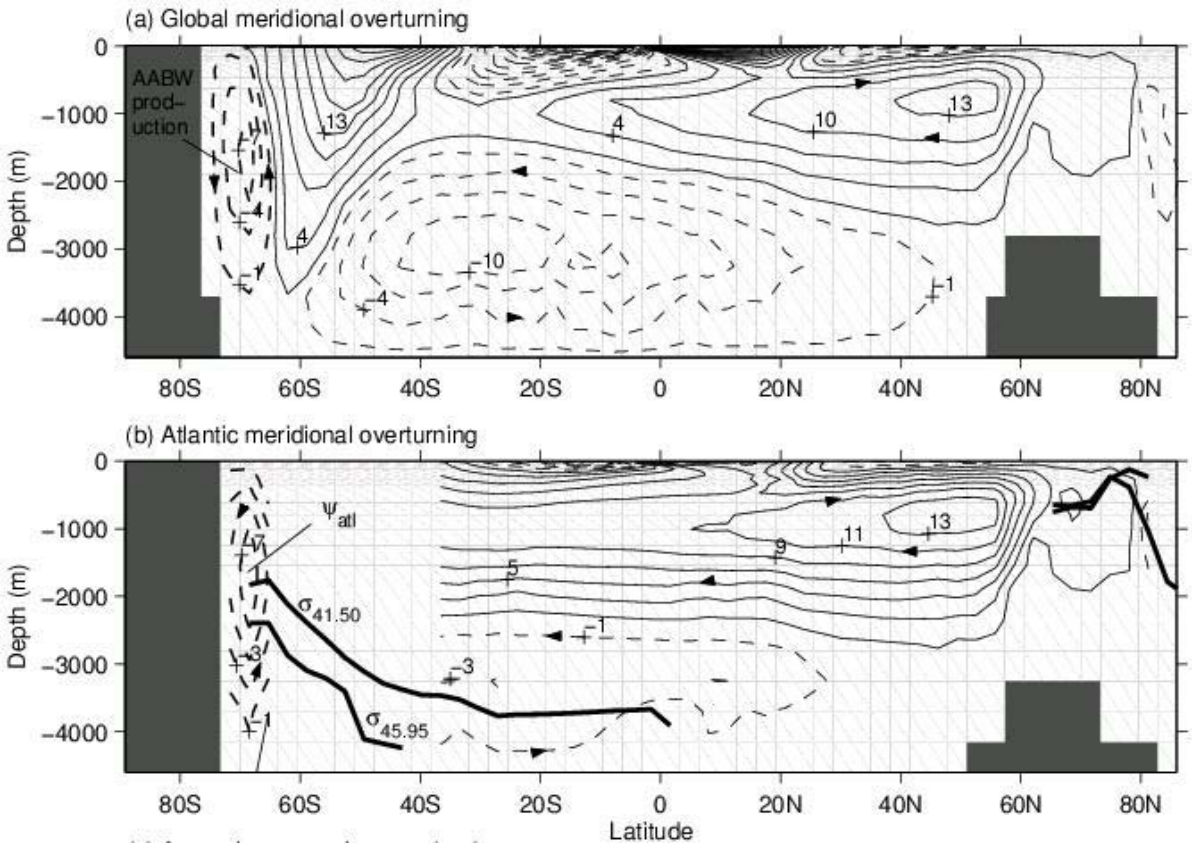
-5
-6
-7
-8
-9
-10



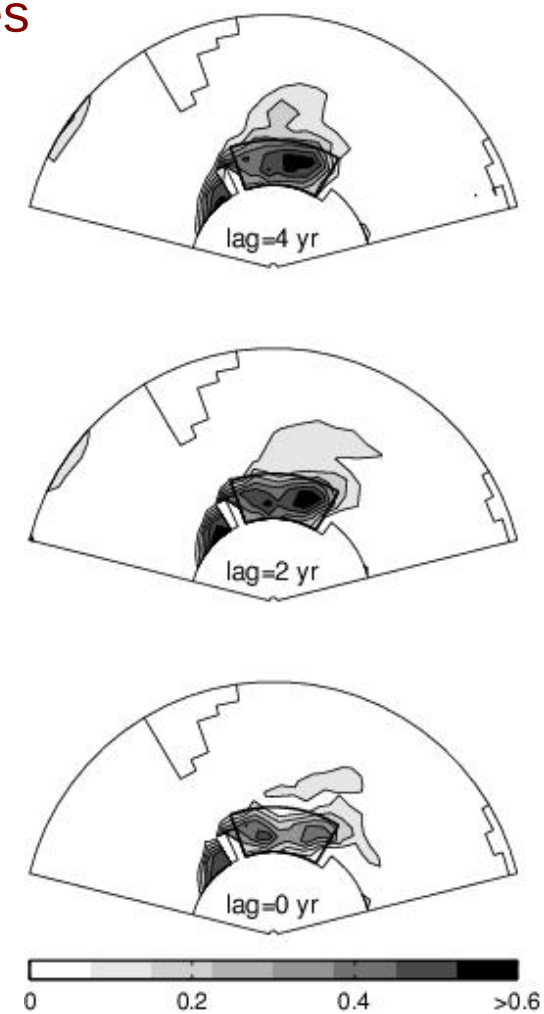
Rintoul and England [2002, JPO, 1308-1321]

Antarctic Bottom Water

Representation of AABW formation and outflow by Antarctic overturning



Overturning variability linked to surface buoyancy anomalies

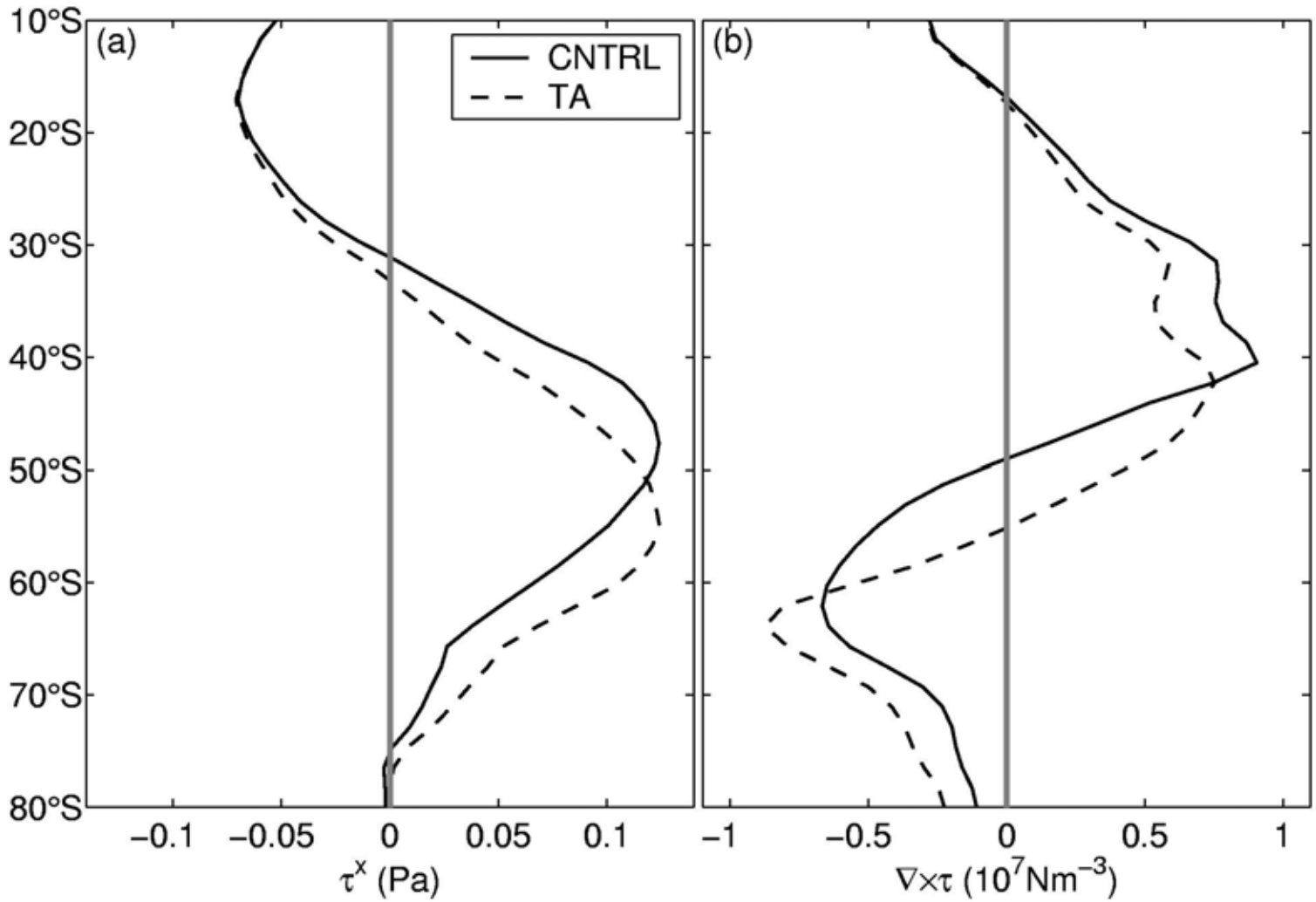


Santoso and England (2008) JPO, in press

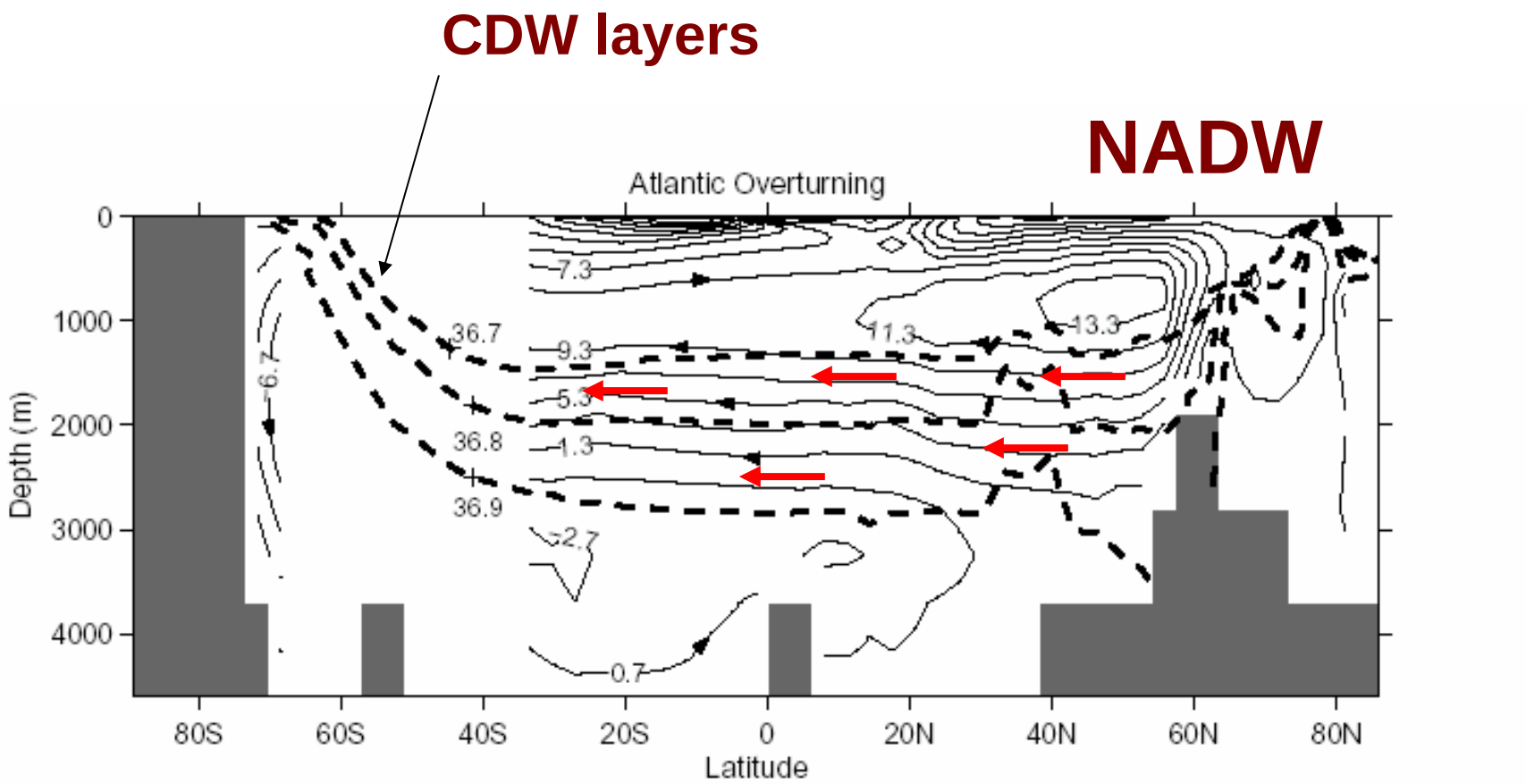
Role of the poleward shift in subpolar westerly winds?

Oke and England [2004, J Clim]

Zonal mean zonal wind stress:



Circumpolar Deep Water



* Santoso, England, Hirst (JPO, 2006)