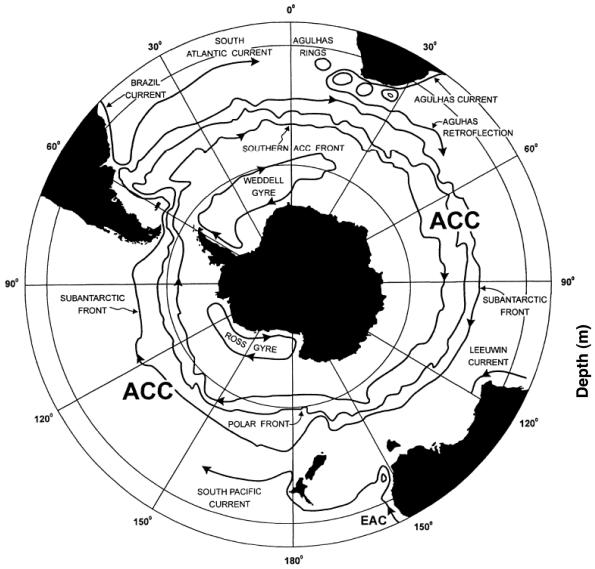
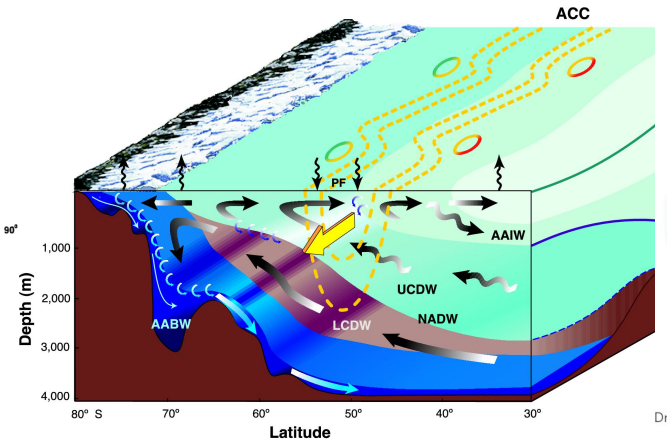
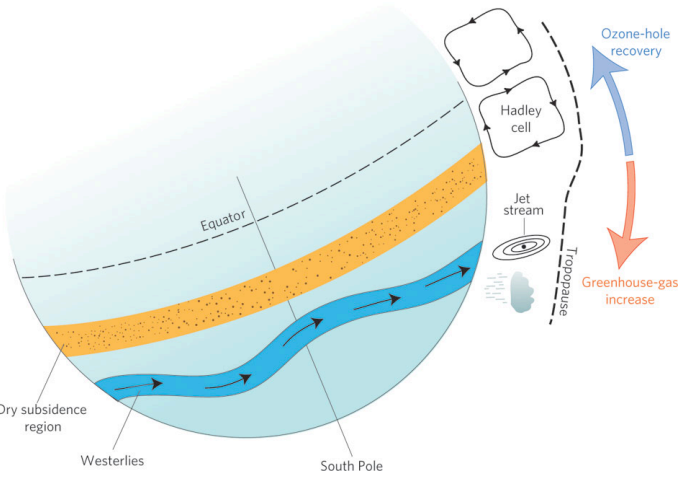
Imprint of the Southern Annular Mode on the coupled ocean-atmosphere-ice system

Matthew England
UNSW Sydney Australia







Climate Change Research Centre

Matthew England
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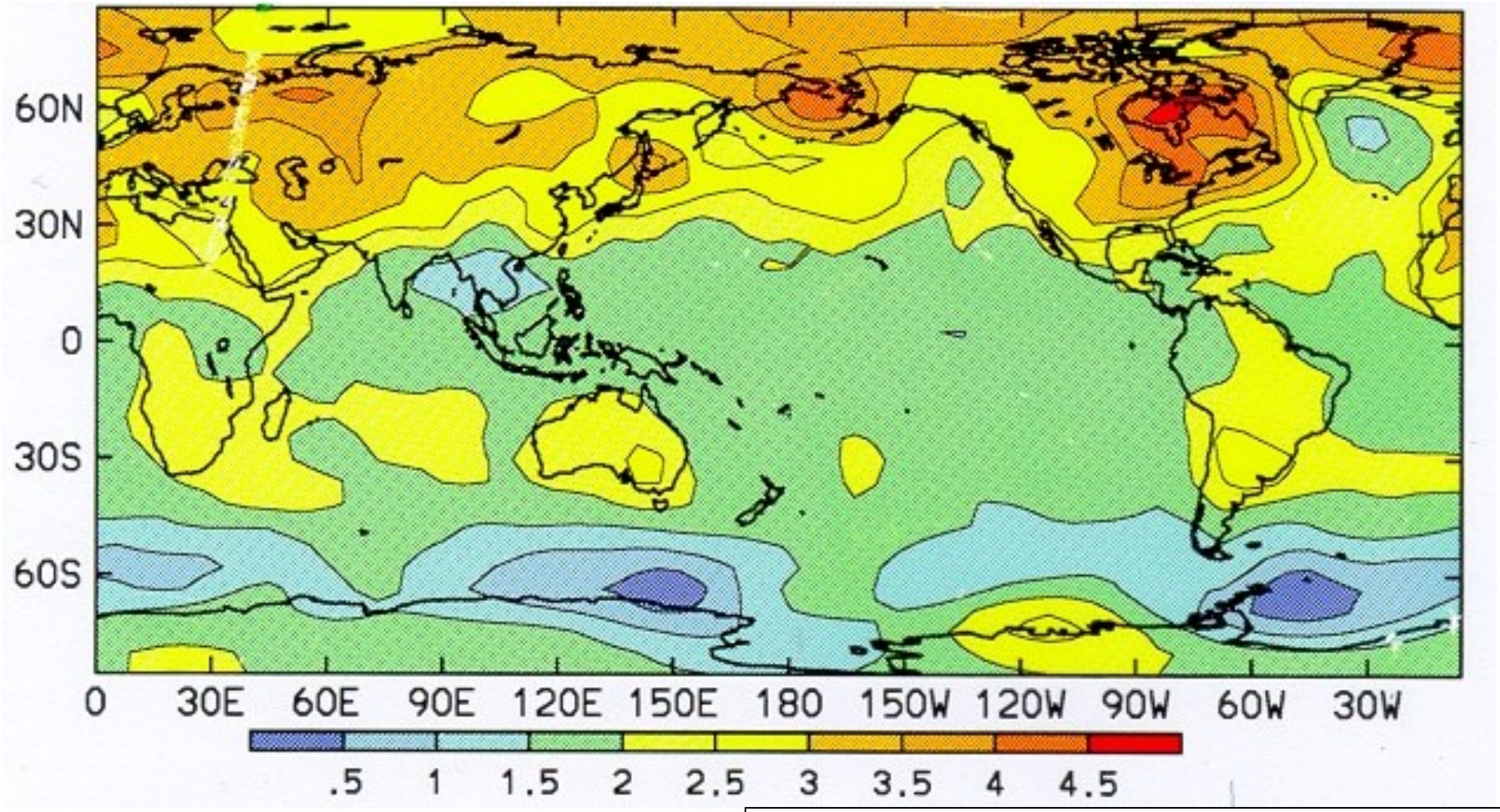
Stouffer et al., 1989

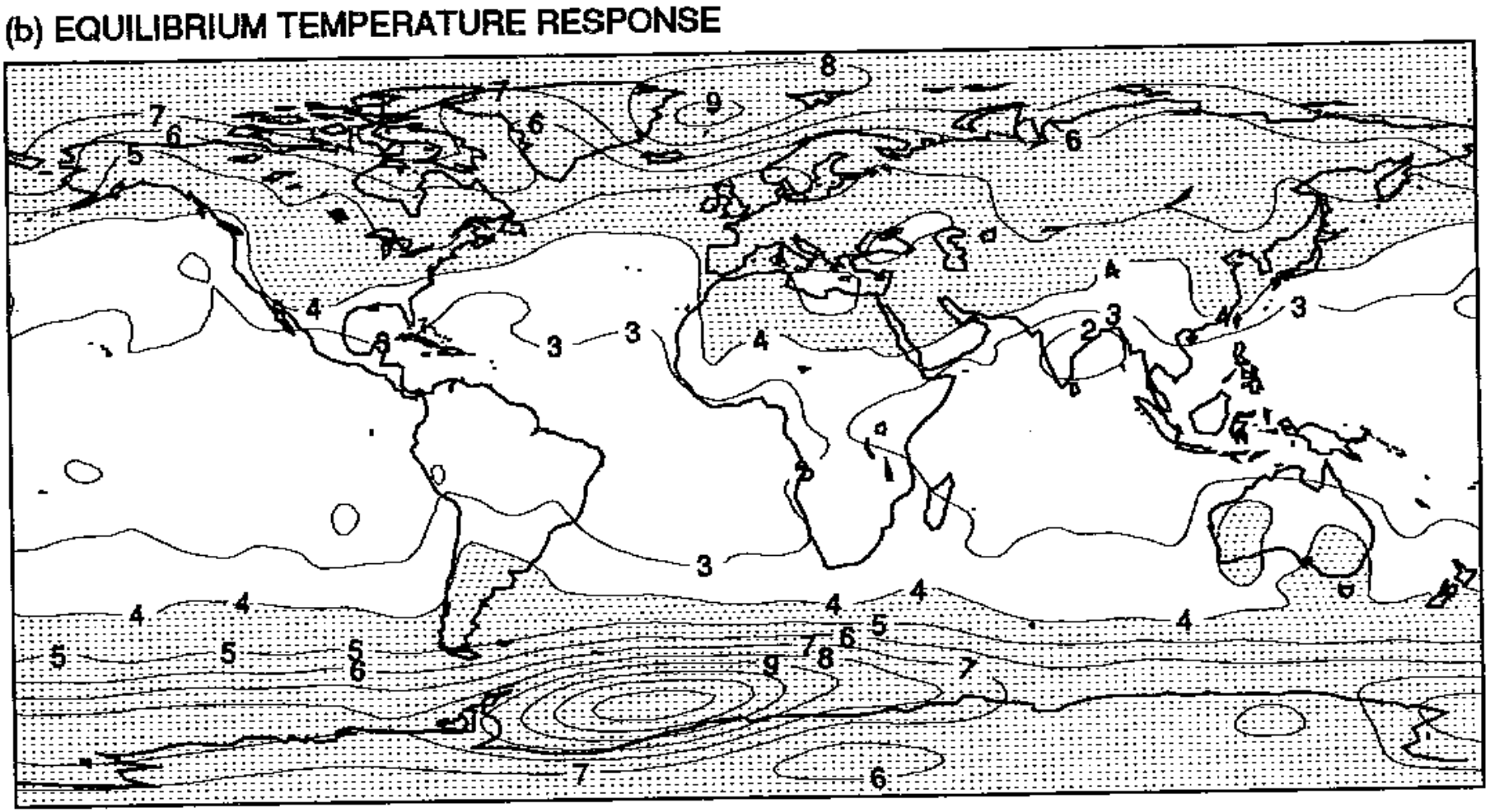


Annual-mean temperature change predicted for around 2050 in the GFDL coupled climate model experiment.

Interhemispheric asymmetry in climate response to a gradual increase of atmospheric CO_2

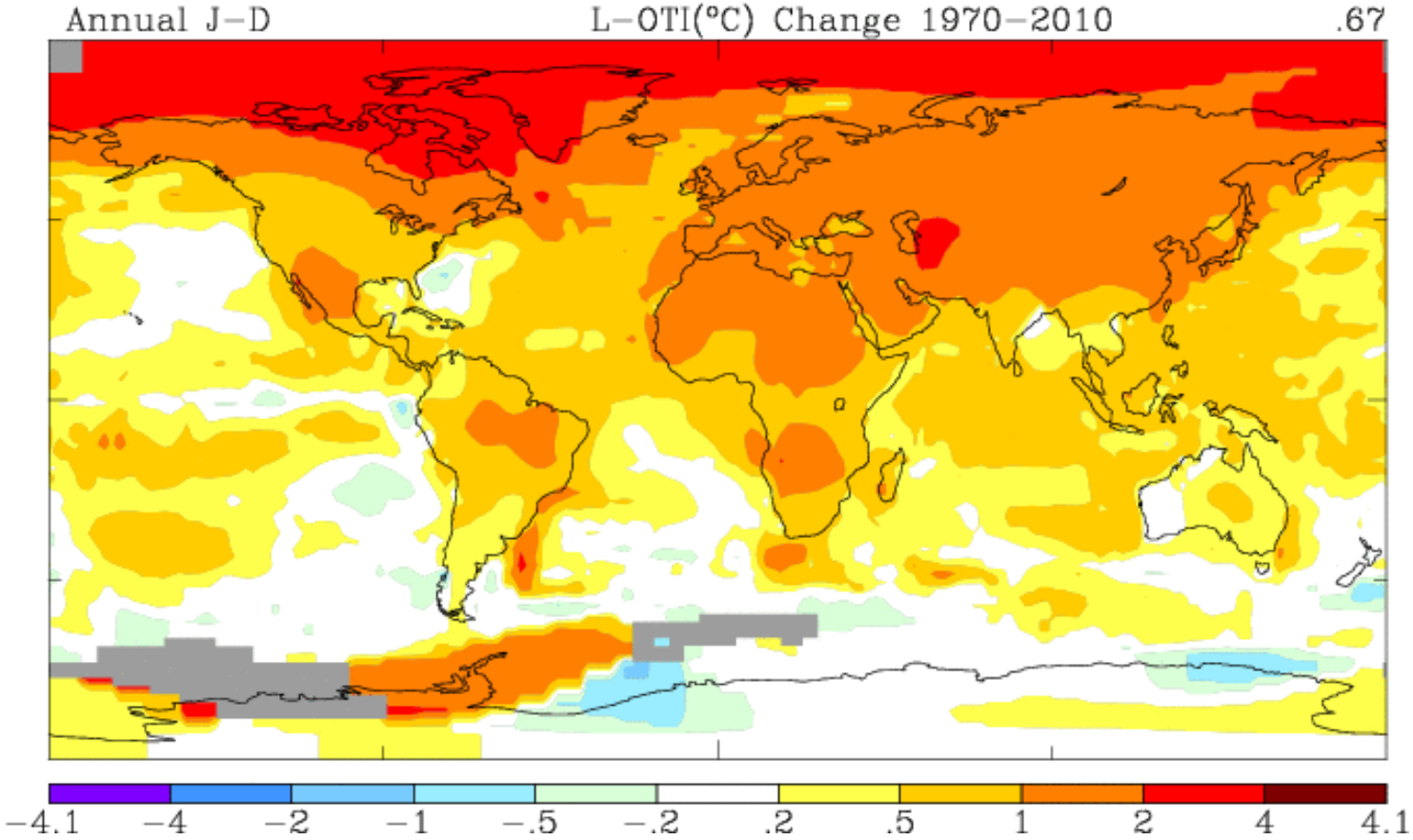
R. J. Stouffer, S. Manabe & K. Bryan

IPCC First Assessment Report (1990)



(b) The equilibrium response of surface air temperature (°C) in the atmosphere-mixed-layer ocean model to a doubling of atmospheric CO_2.

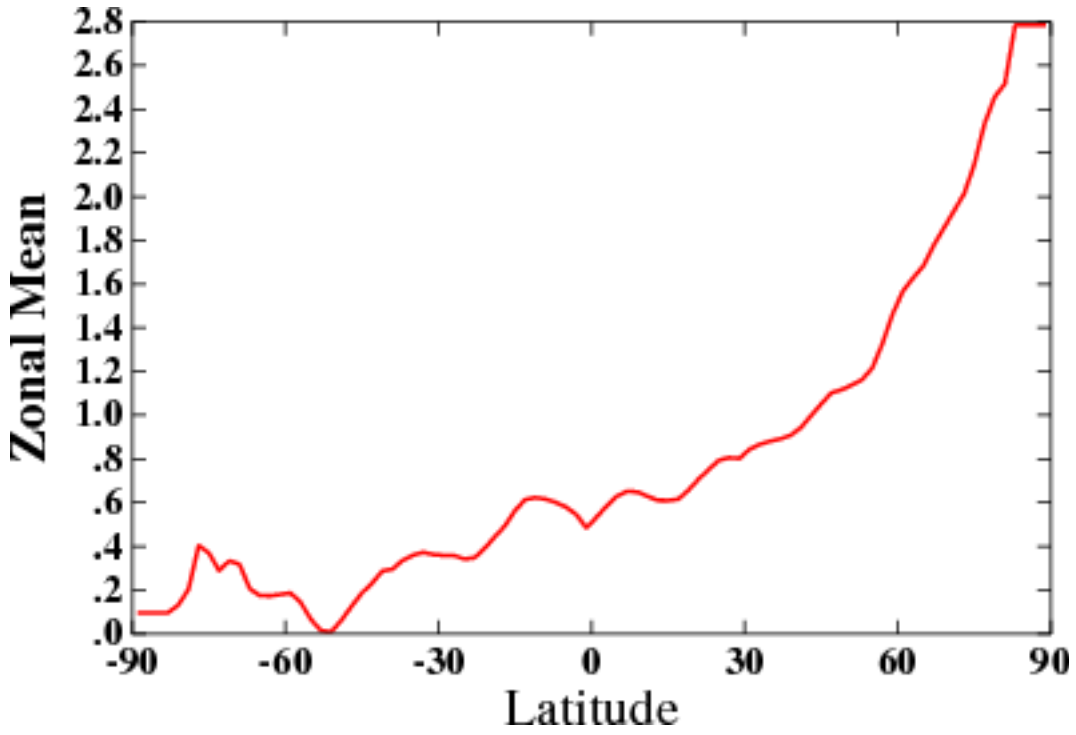
Observed surface air temperature trends….



1970 – 2010 trends in annual mean SAT

http://data.giss.nasa.gov/gistemp/maps/

Observed SAT trends….



1970 – 2010 trends in annual mean SAT

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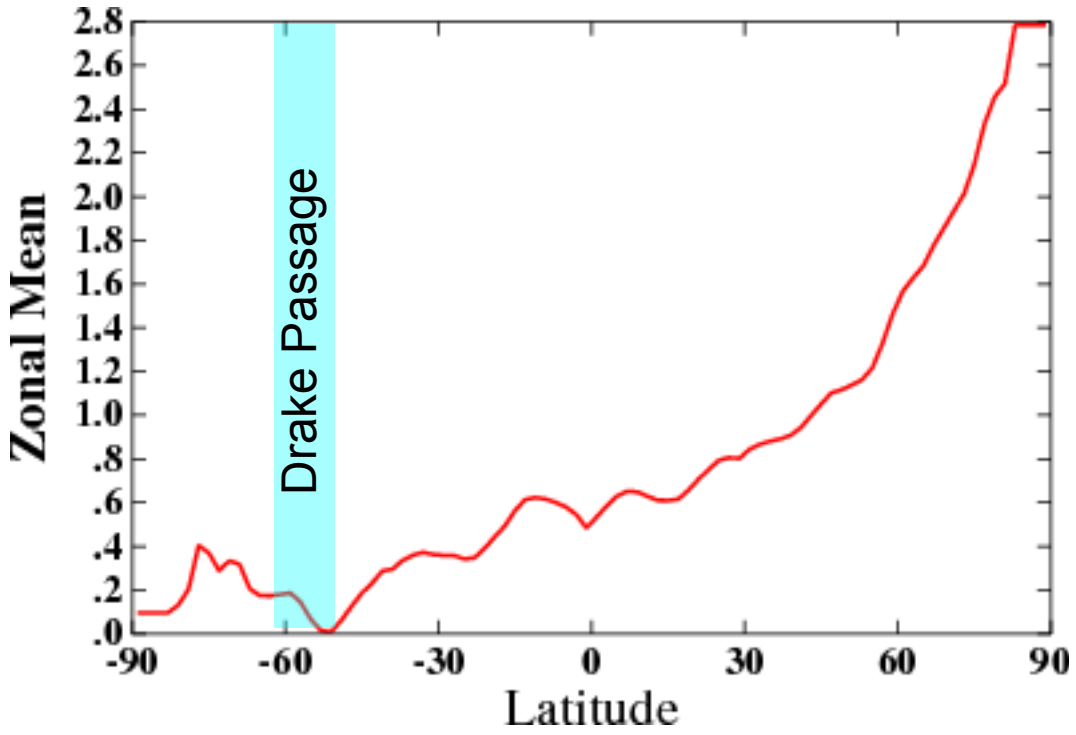
Observed SAT trends….



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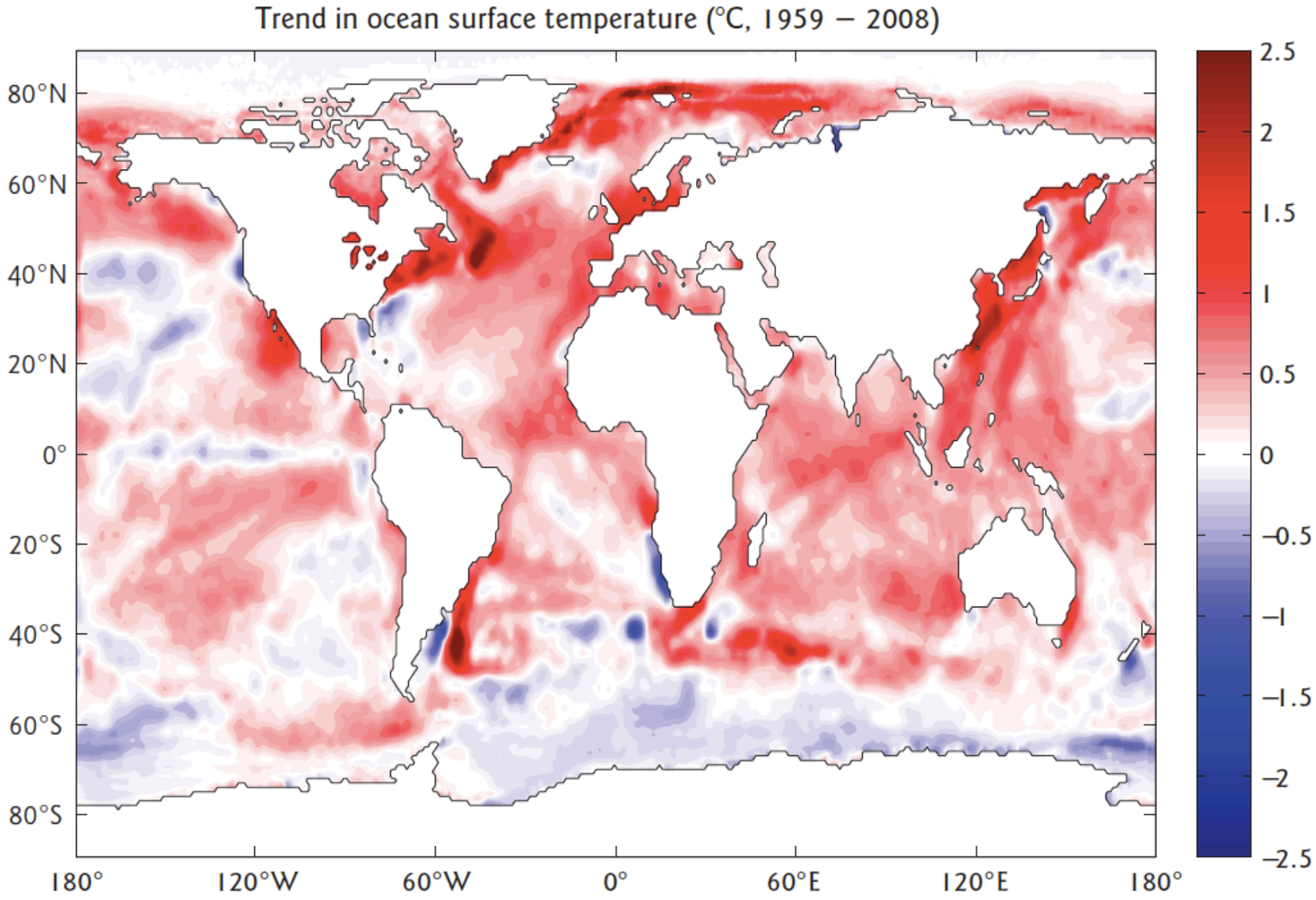
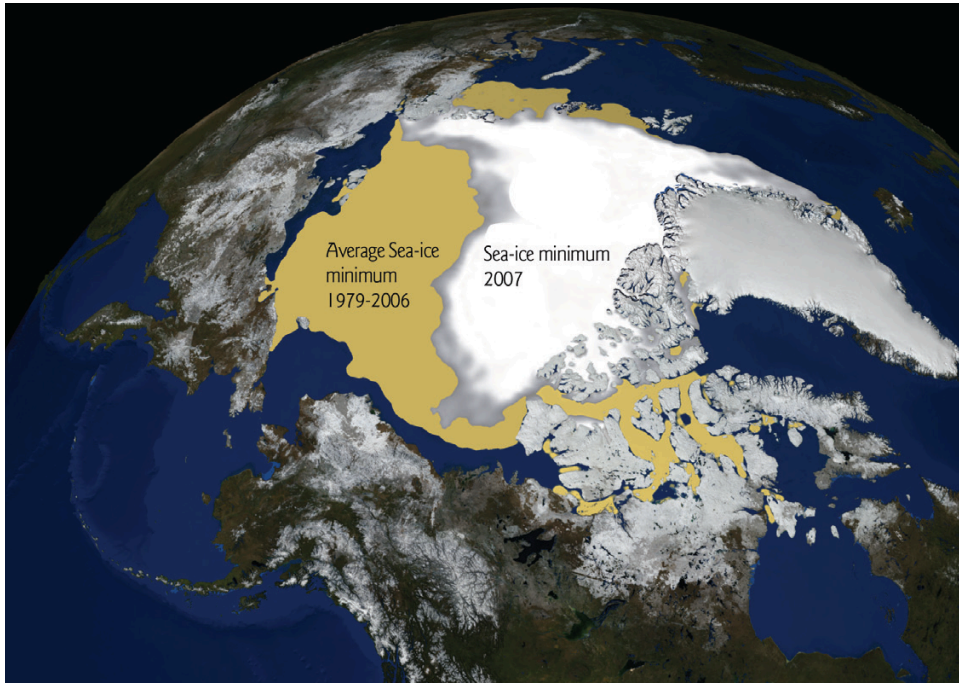


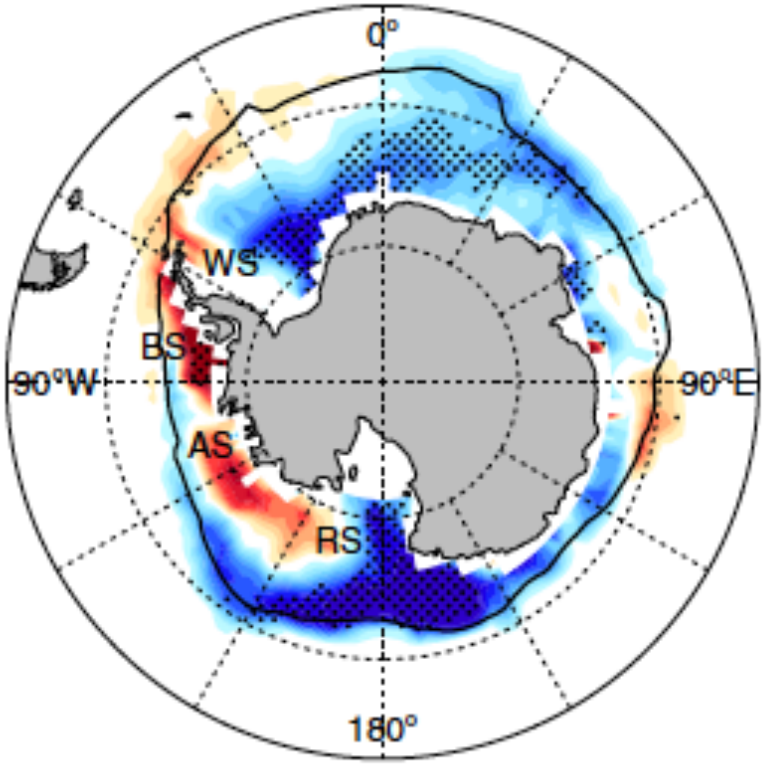
Figure 15. Long-term 50-year change in sea surface temperature (SST) during 1959-2008 calculated by fitting a linear trend to 50 years of monthly SST data at each grid point. The SST fields are from the Hadley Centre data set as described by Rayner et al. (2006).

England et al. (2009; Copenhagen Diagnosis)

Marked sea-ice trends across the hemispheres



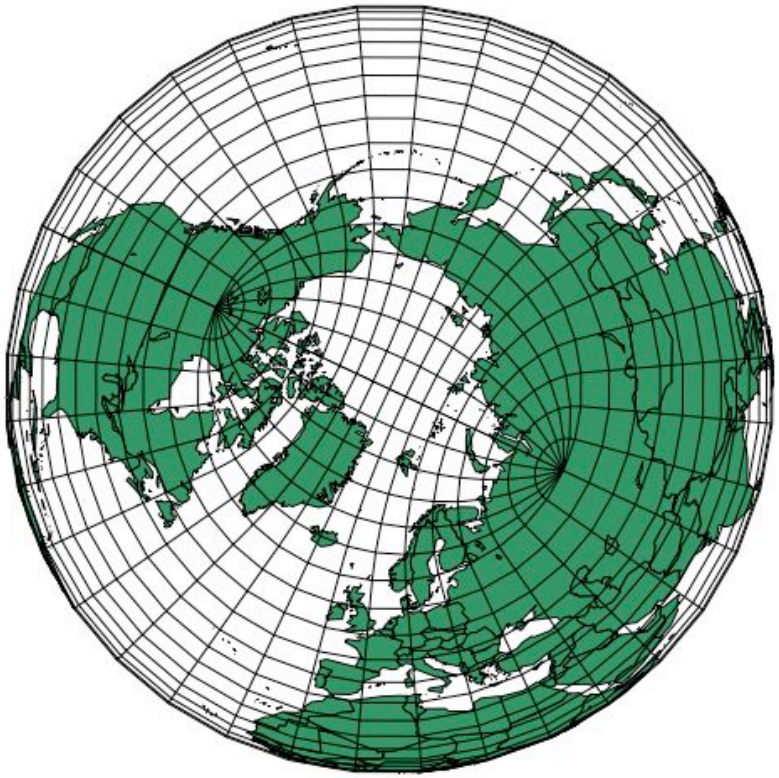
Average sea-ice 1979–2006 and then in 2007

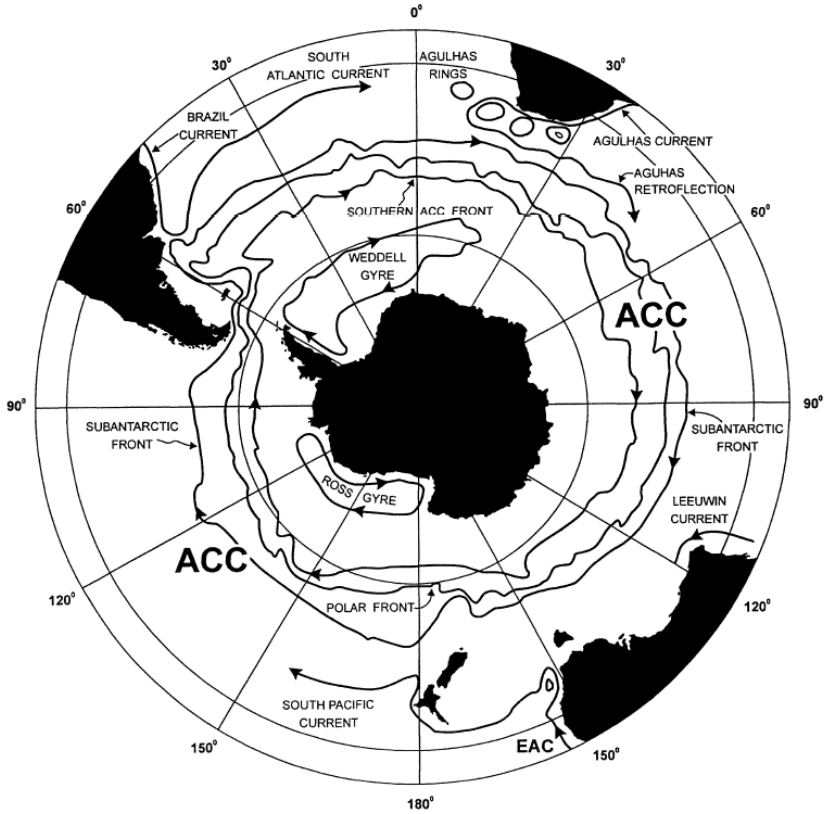


Annual SIC trends 1979–2013

Purich et al. 2016

Marked geometry contrast across the hemispheres





North Pole:

Ocean + sea-ice

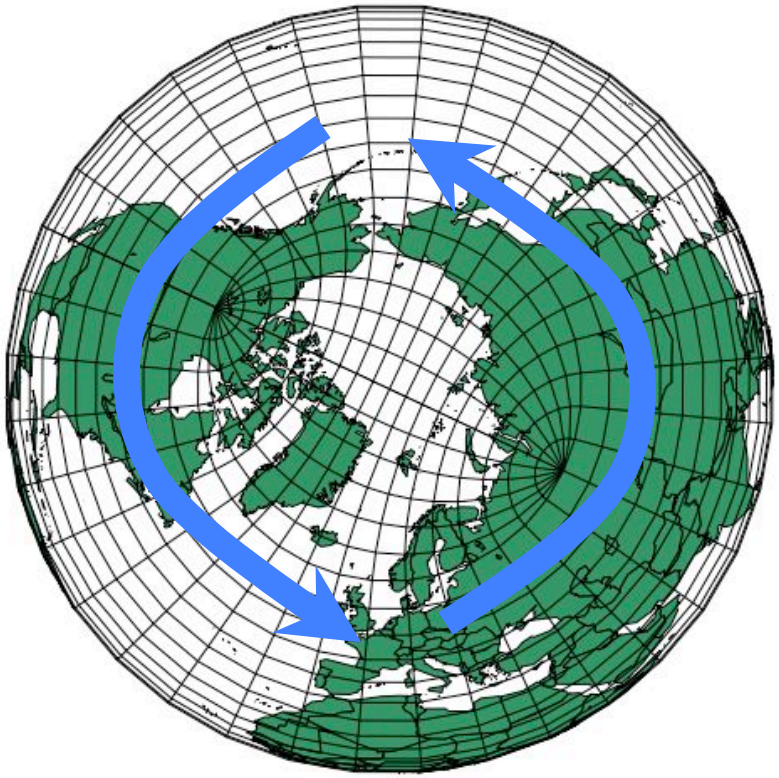
Surrounded by **land**

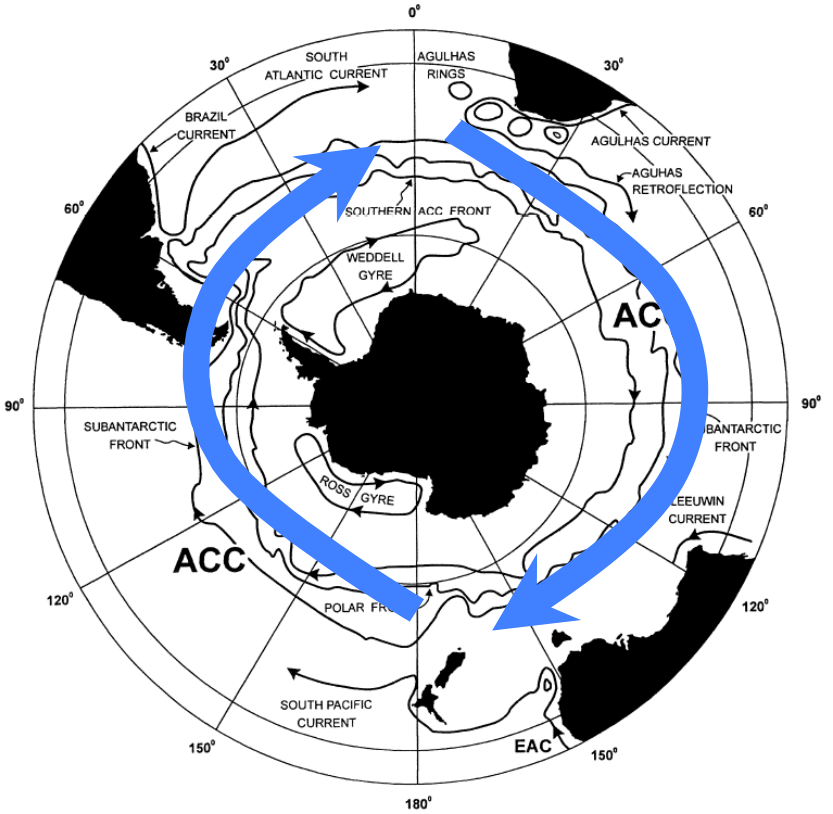
South Pole:

Land mass + Land ice

Surrounded by **oceans**

Marked geometry contrast across the hemispheres





North Pole:

Ocean + sea-ice

Surrounded by **land**

South Pole:

Land mass + Land ice

Surrounded by **oceans**

Due to trends in the Southern Annular Mode…?

ODS-only

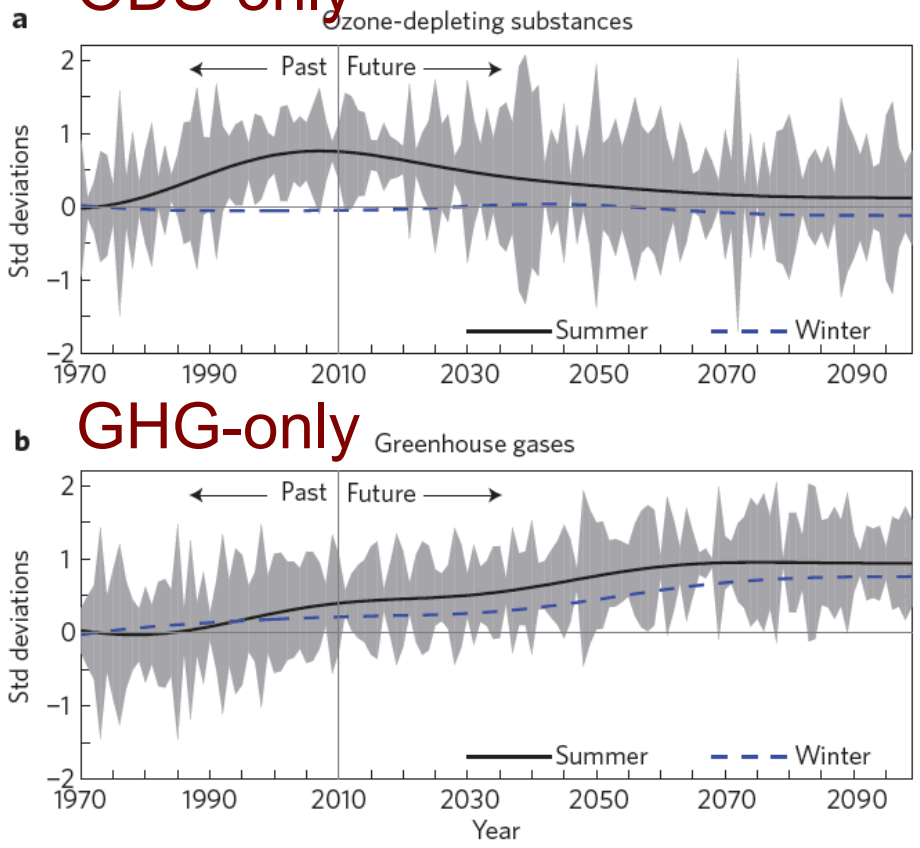
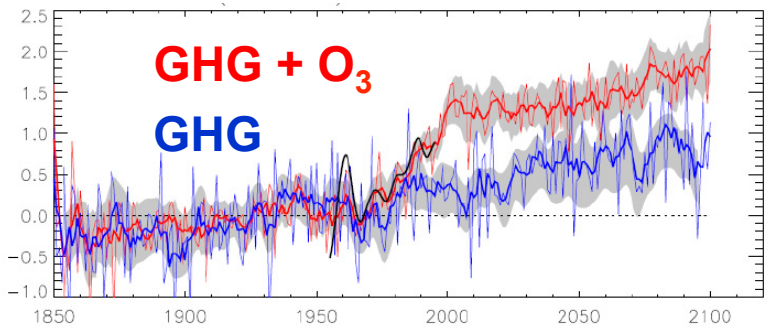


Figure 3 | Time series of the southern annular mode from transient experiments forced with time-varying ozone-depleting substances and greenhouse gases. Results are from experiments published in ref. 28.

IPCC 2007



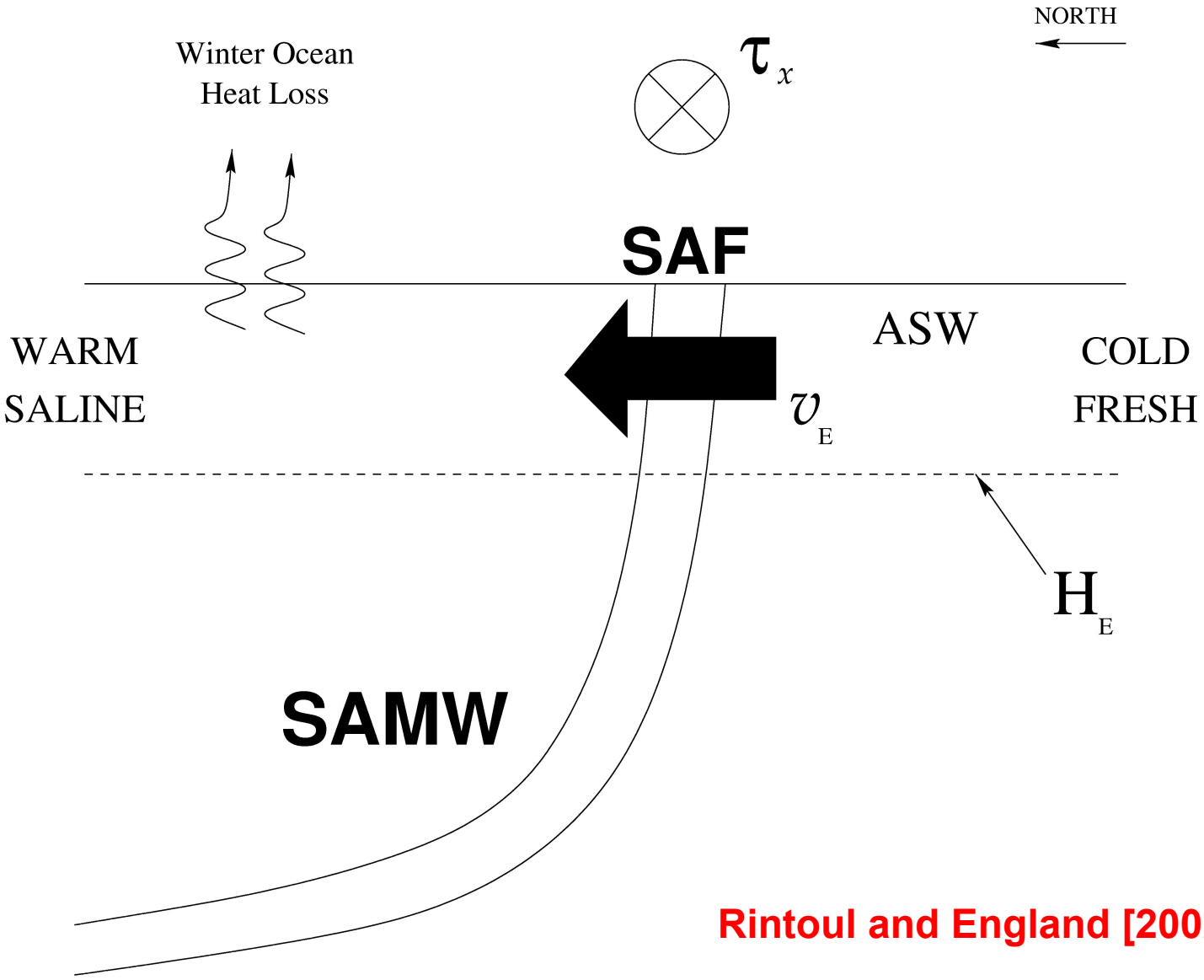
Multi-model SAM index (Nov-Feb)

nature geoscience
REVIEW ARTICLE
PUBLISHED ONLINE: 23 OCTOBER 2011 | DOI: 10.1038/NGEO1296

Signatures of the Antarctic ozone hole in Southern Hemisphere surface climate change

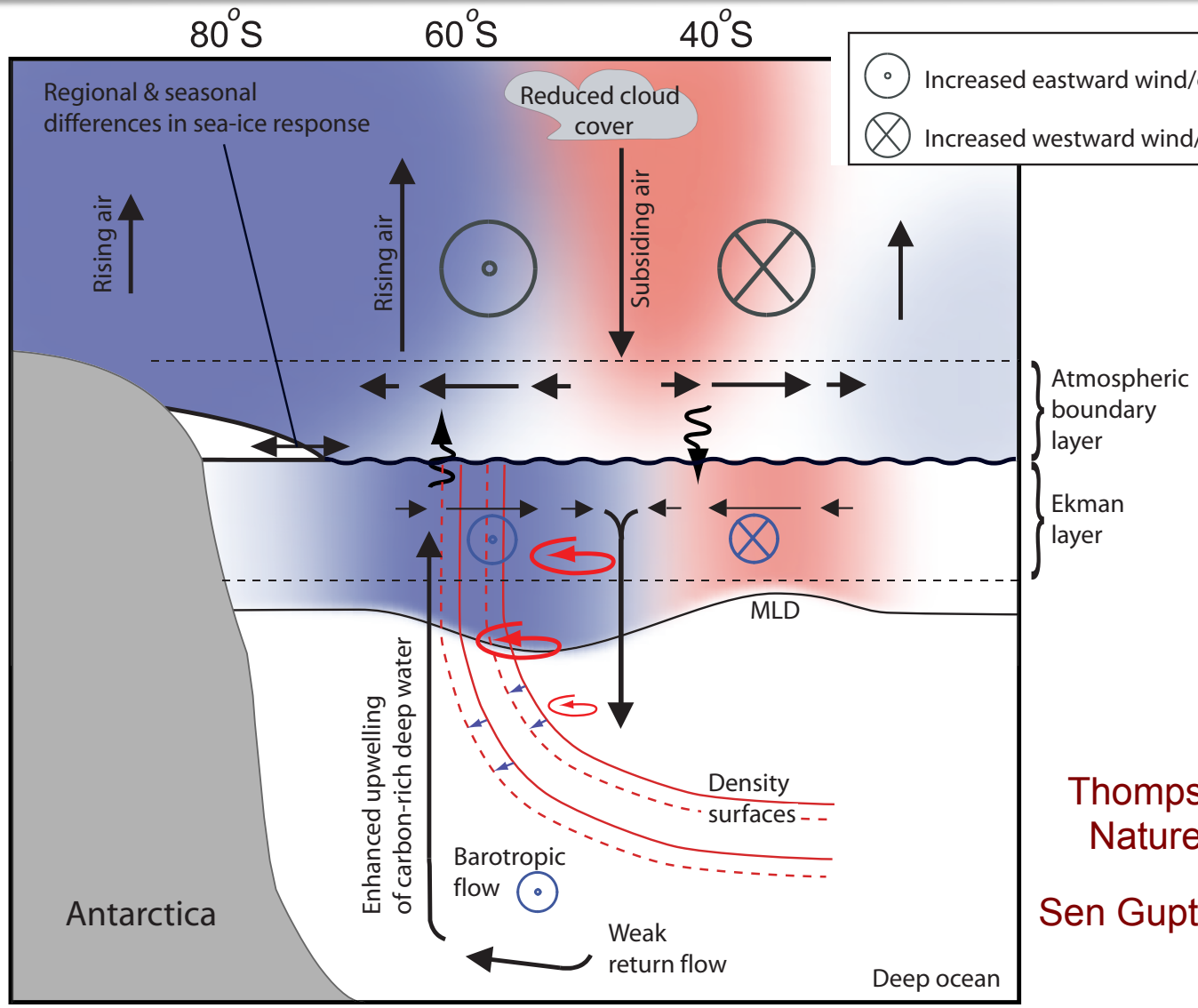
David W. J. Thompson[1*], Susan Solomon[2,3], Paul J. Kushner[4], Matthew H. England[5], Kevin M. Grise[1] and David J. Karoly[6]

Imprint of wind trends on Southern Ocean circulation…?



Rintoul and England [2002] JPO

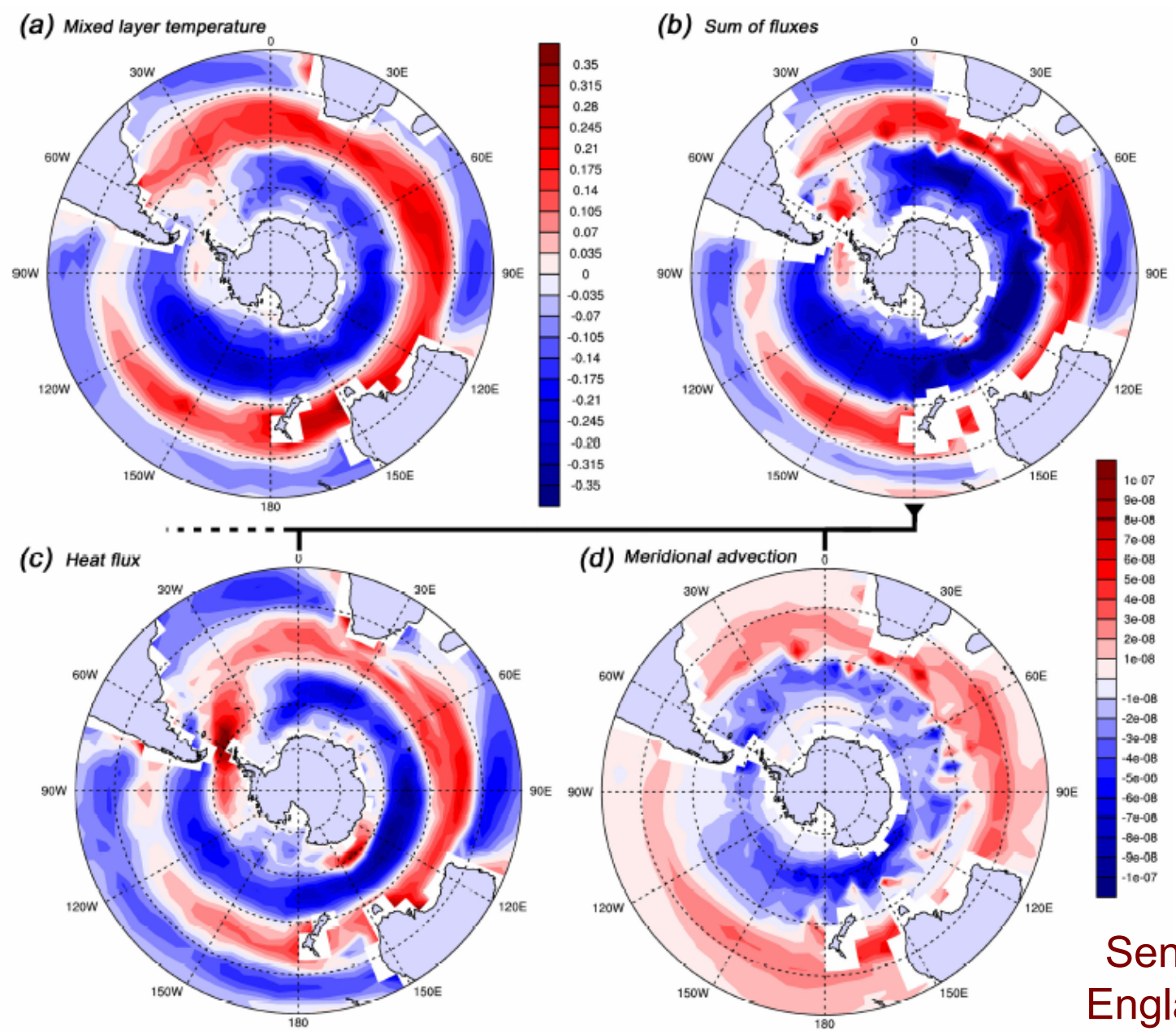
Ocean-atmosphere imprint of the Southern Annular Mode



Surface fluxes, Ekman transport and MLD changes act in concert to produce SST response. Eddy heat fluxes act in the opposite sense

Thompson et al. (2011) Nature Geosciences

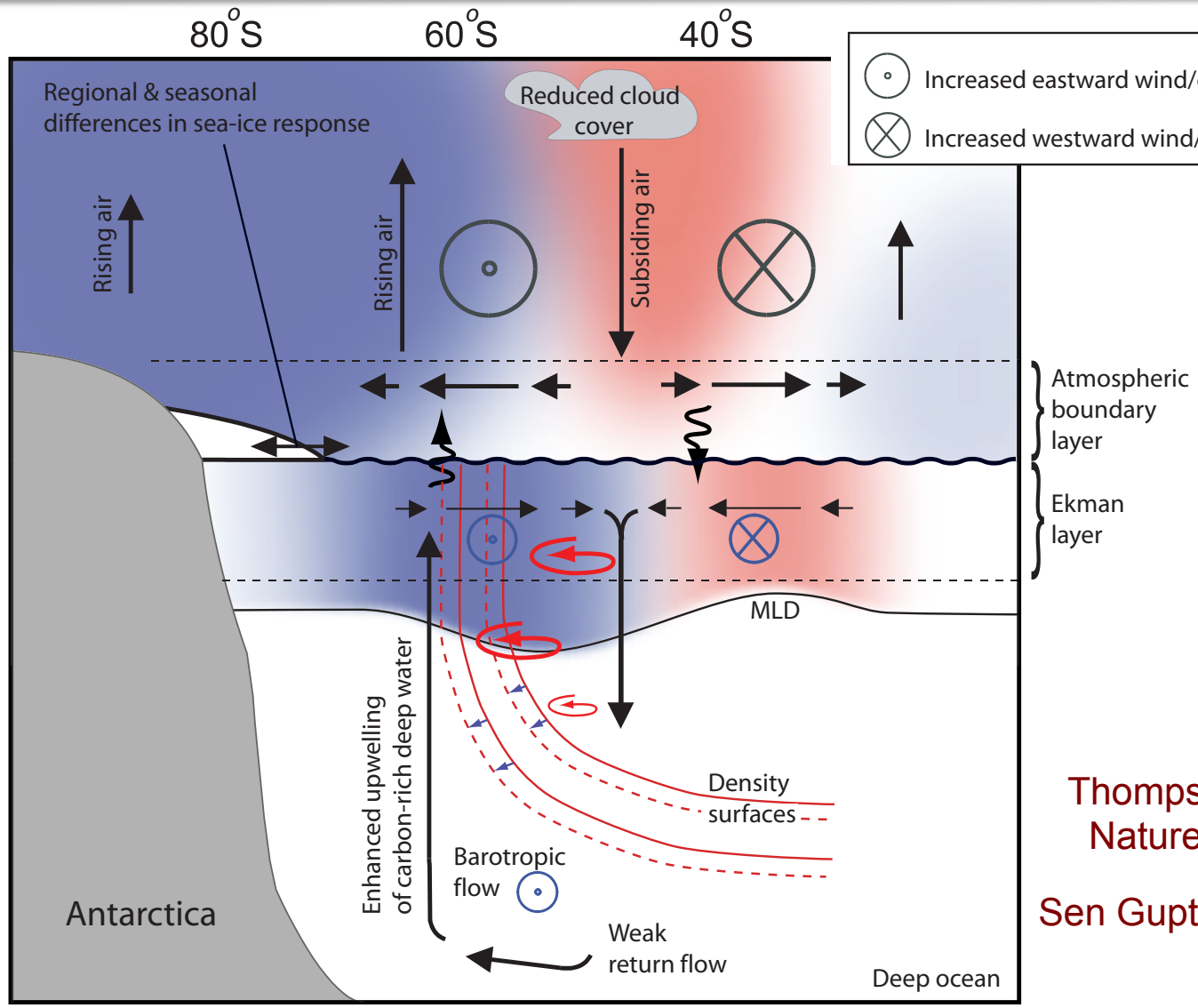
Sen Gupta and England (2006)



Sen Gupta & England 2006

FIG. 13. Regressions on the SAM index of (a) mixed layer temperature (°C), (b) sum of mixed layer heat budget terms (°C s^{-1}), (c) net surface heat flux term (°C s^{-1}), and (d) meridional heat advection term (°C s^{-1}). Color scaling is identical in (b)–(d).

Ocean-atmosphere imprint of the Southern Annular Mode



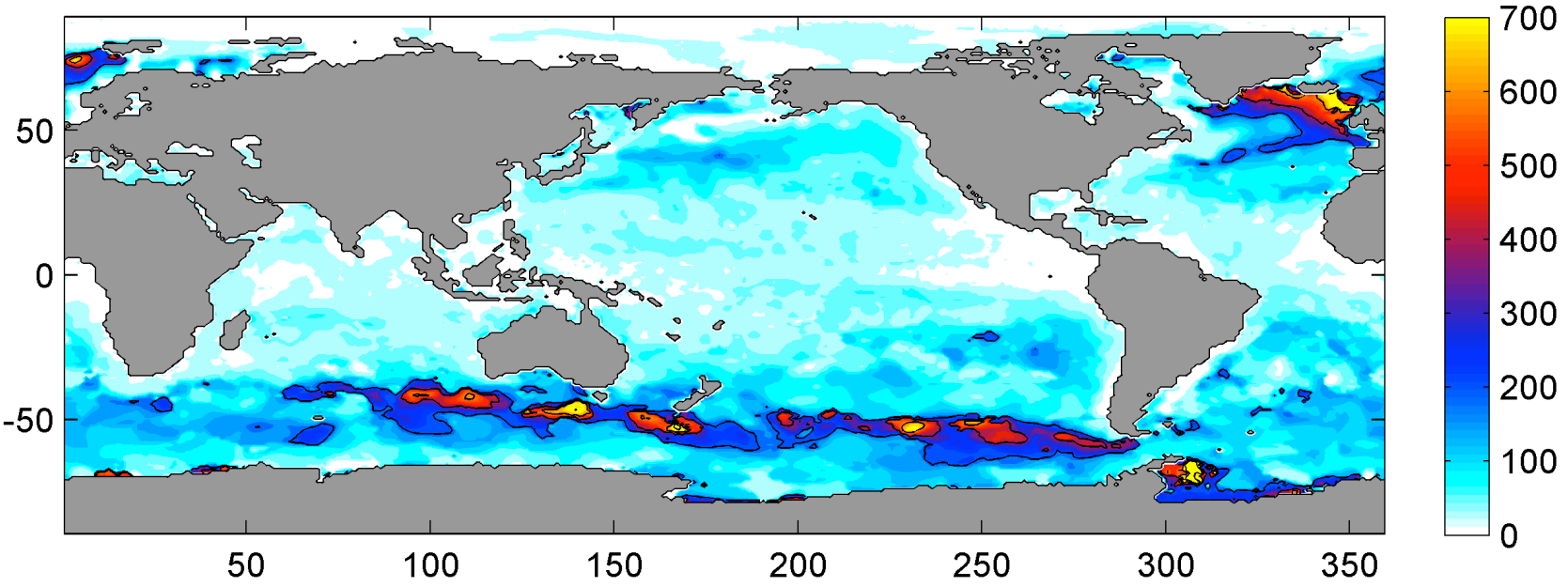
Surface fluxes, Ekman transport and MLD changes act in concert to produce SST response. Eddy heat fluxes act in the opposite sense

Thompson et al. (2011) Nature Geosciences

Sen Gupta and England (2006)

Interhemispheric asymmetry…?

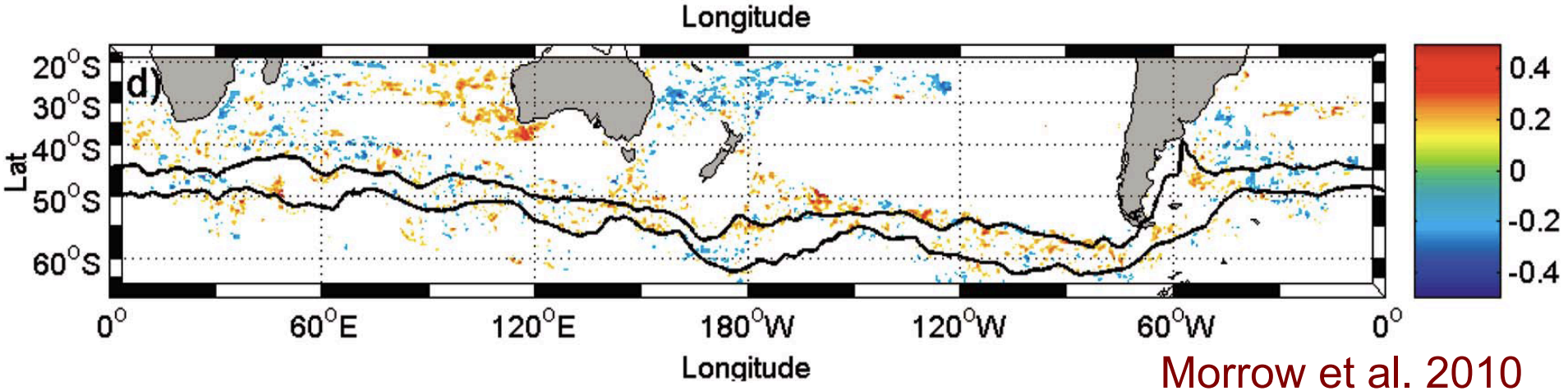
- How much of a role does the DP effect / subduction / deep MLs north of the ACC have?



Maximum mixed layer depth during the year, based on monthly means

Eddy compensation…?

- What is the role of ocean eddies now and into the future…?

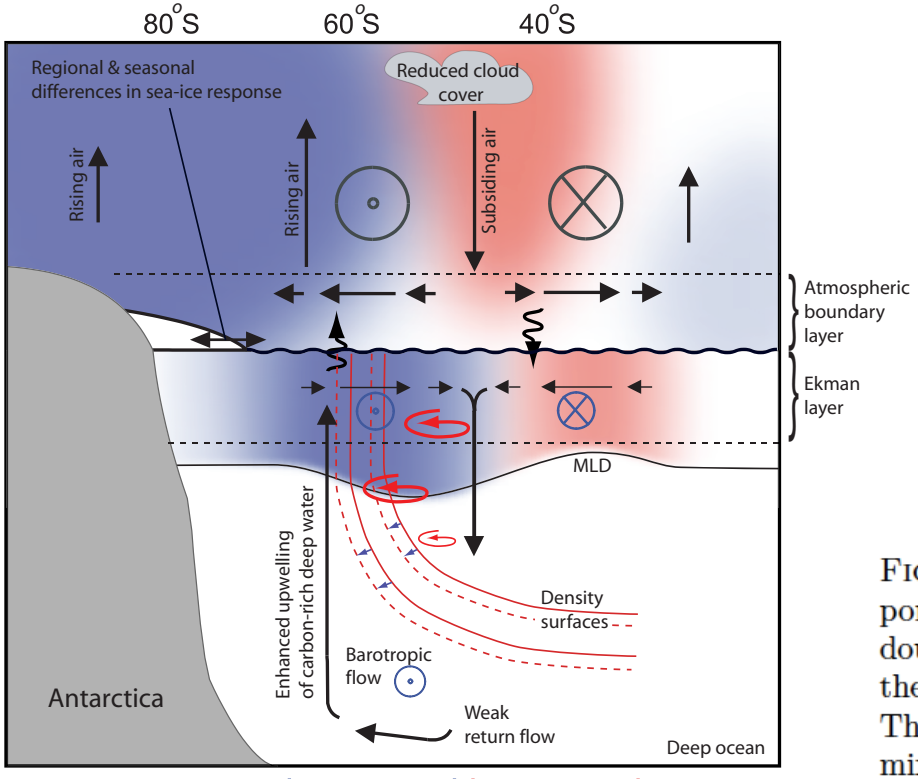


Morrow et al. 2010

Observed 2 year lagged correlation between monthly EKE and the SAM

And also Meredith, Hogg, Morrison, Dufour, Delworth, Gent, Spence, Farneti, ….

Eddies compensate Ekman mass flux but not upper ocean heat fluxes



Sen Gupta and England (2006)

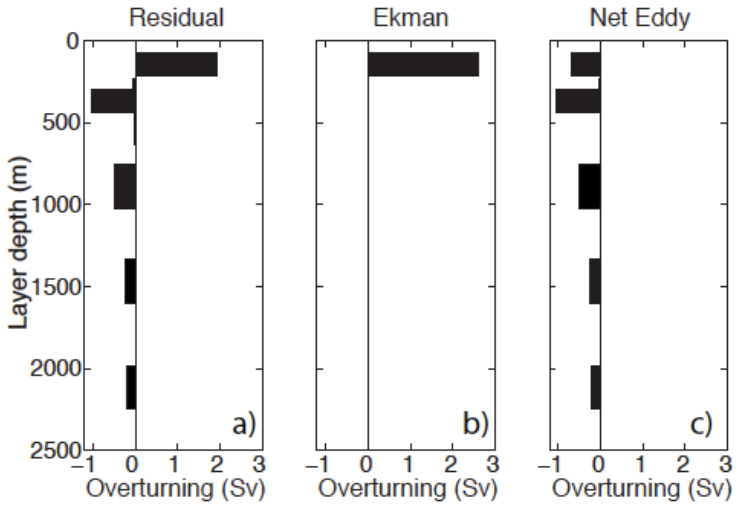
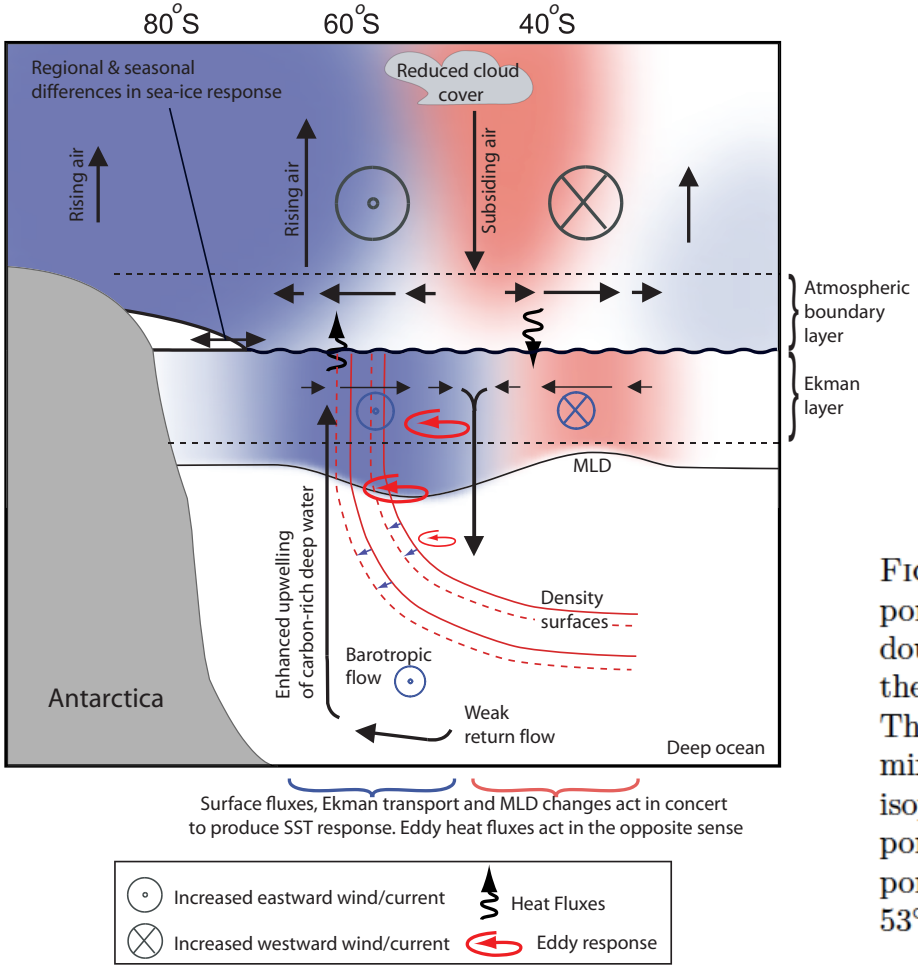


FIG. 6. Depth structure of the changes in meridional transport at 53°S in the $^1/_{12}°$ simulation as a result of wind stress doubling from $\tau = 0.12 \rightarrow 0.24$ Nm^{-2}. Only the portion of the overturning above the depth of topography is shown. The top bar in each figure shows transport in the bulk mixed layer, while lower bars show transport in interior isopycnal layers. Positive values reflect northward transport. a) The zonally averaged, residual meridional transport ($\overline{vh}$). b) Theoretically calculated Ekman transport at 53°S ($\tau/\rho f$). c) Net eddy-induced overturning ($\overline{vh} - \tau/\rho f$).

Morrison and Hogg (2013)

Eddies compensate Ekman mass flux but not upper ocean heat fluxes



Sen Gupta and England (2006)

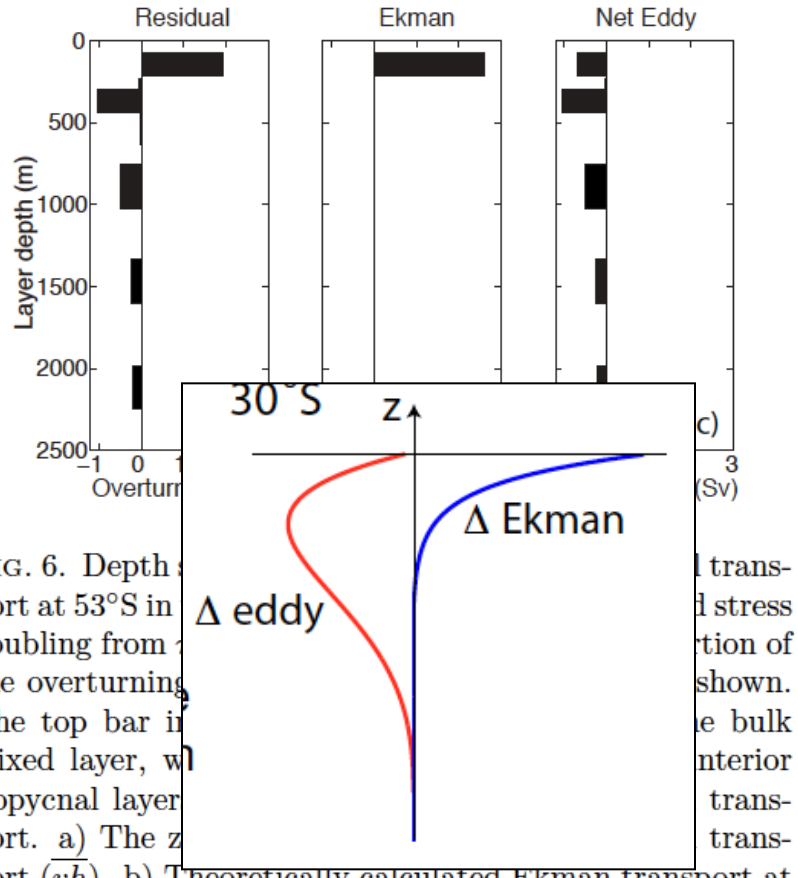
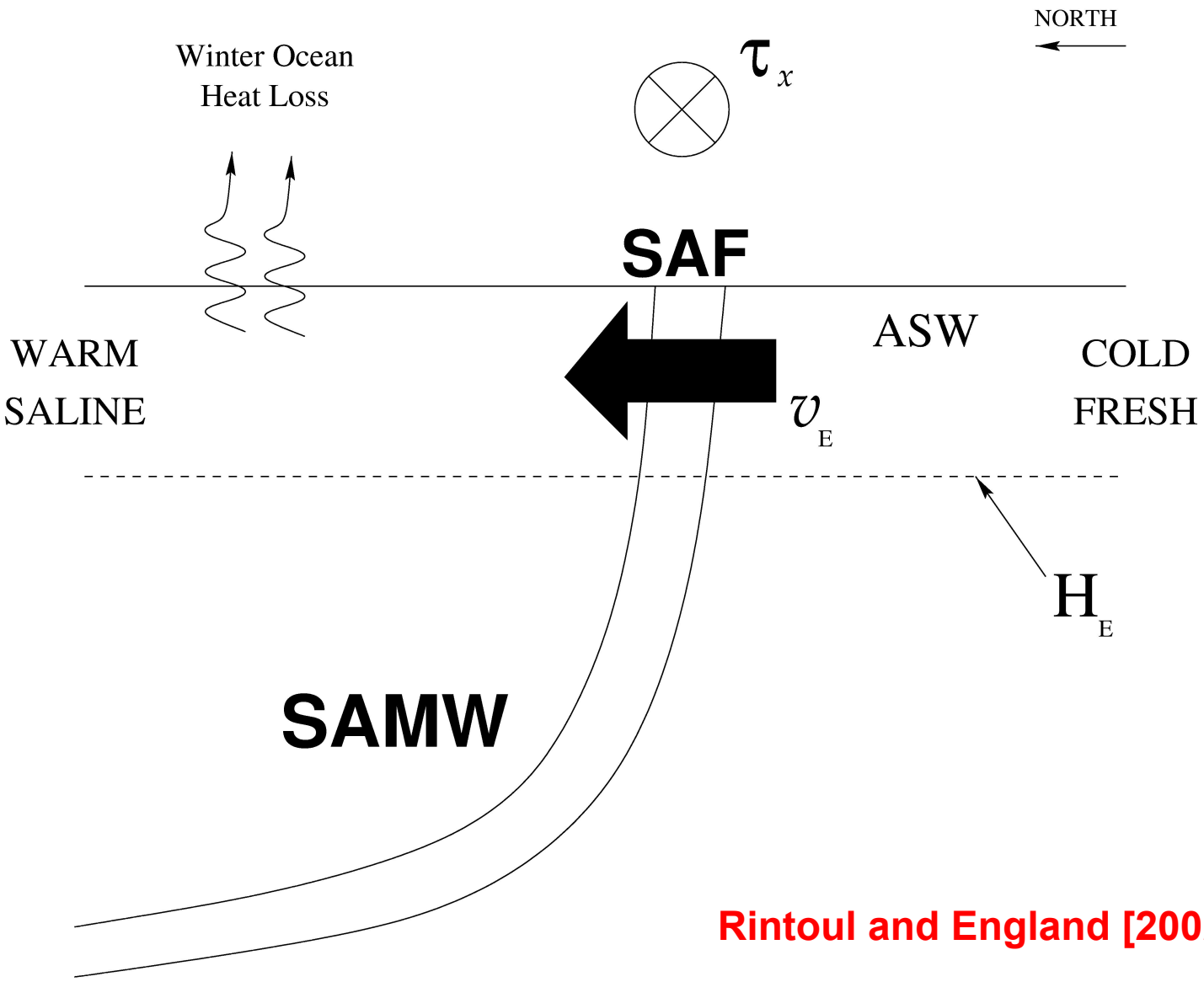


FIG. 6. Depth … l trans-
port at 53°S in … l stress
doubling from … rtion of
the overturning … shown.
The top bar i… e bulk
mixed layer, w… nterior
isopycnal layer… trans-
port. a) The z… trans-
port ($\overline{vh}$). b) Theoretically calculated Ekman transport at 53°S ($\tau/\rho f$). c) Net eddy-induced overturning ($\overline{vh} - \tau/\rho f$).

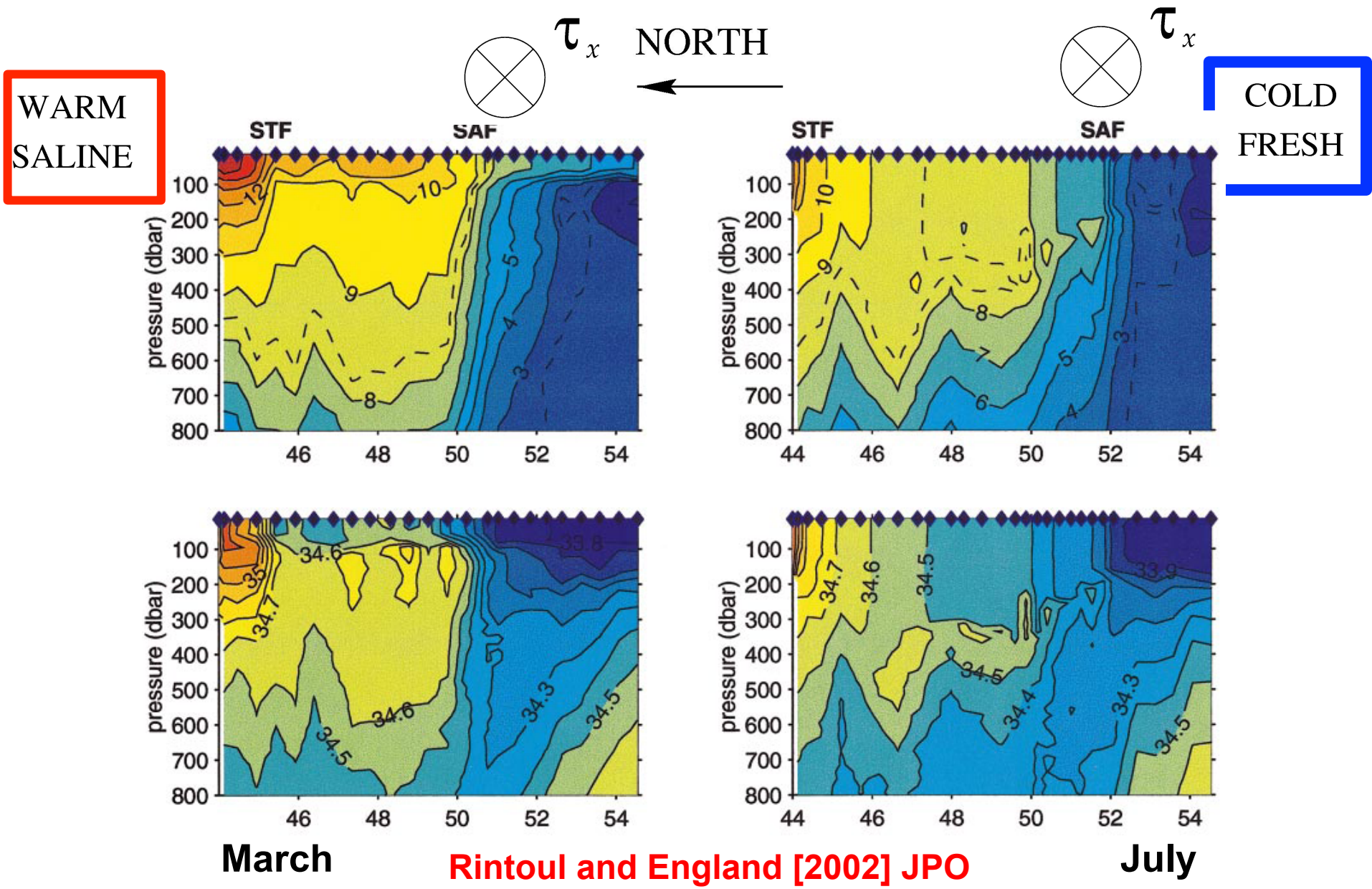
Morrison and Hogg (2013)

Imprint of wind trends on Southern Ocean T-S…?



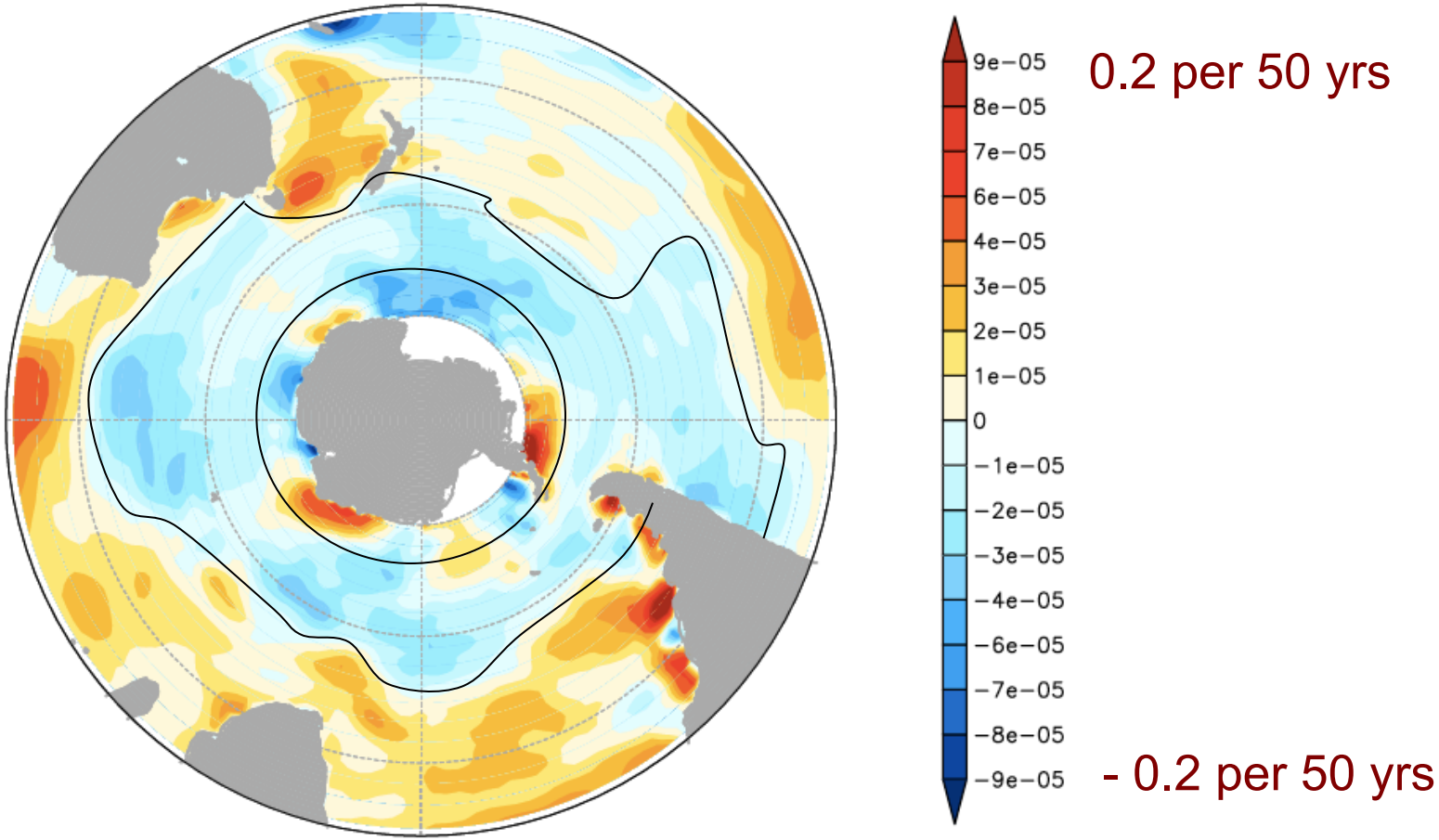
Rintoul and England [2002] JPO

Imprint of wind trends on Southern Ocean T-S…?



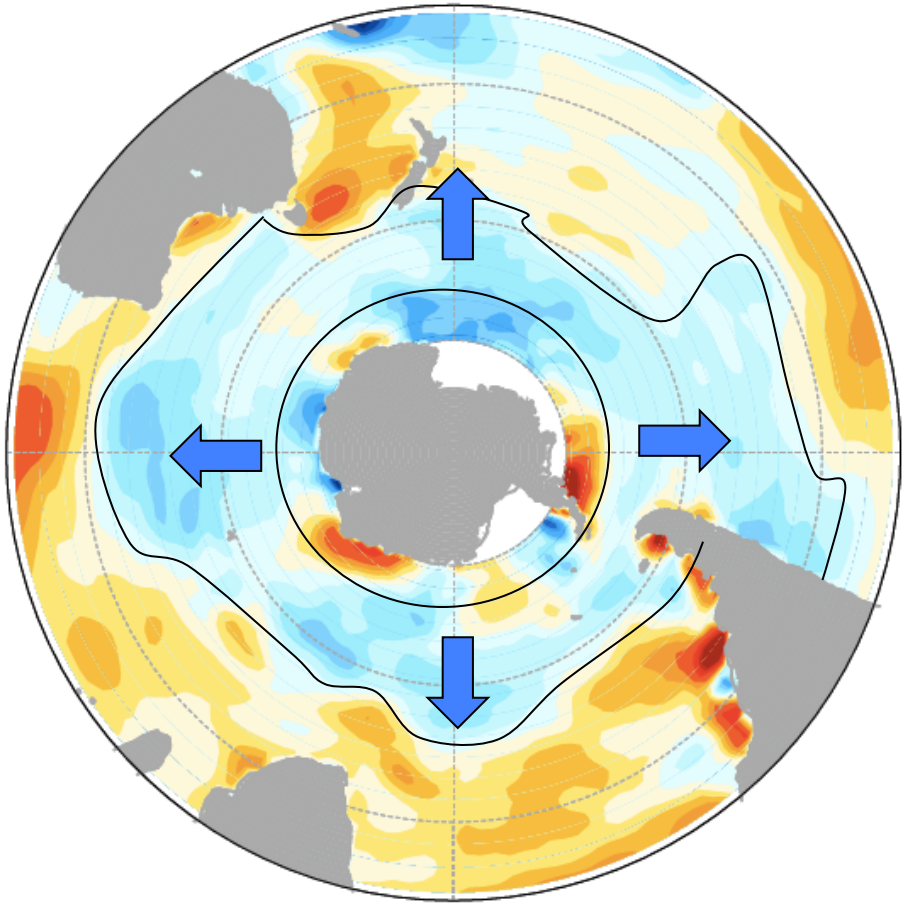
Rintoul and England [2002] JPO

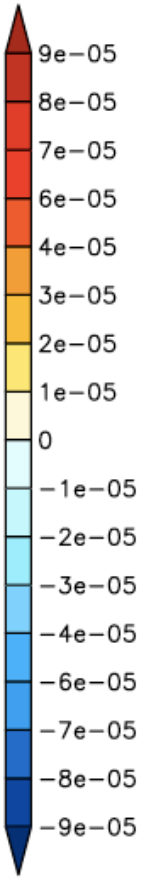
Salinity trends 1950-2000



Durack and Wijffels (2010)

Salinity trends 1950-2000





0.2 per 50 yrs

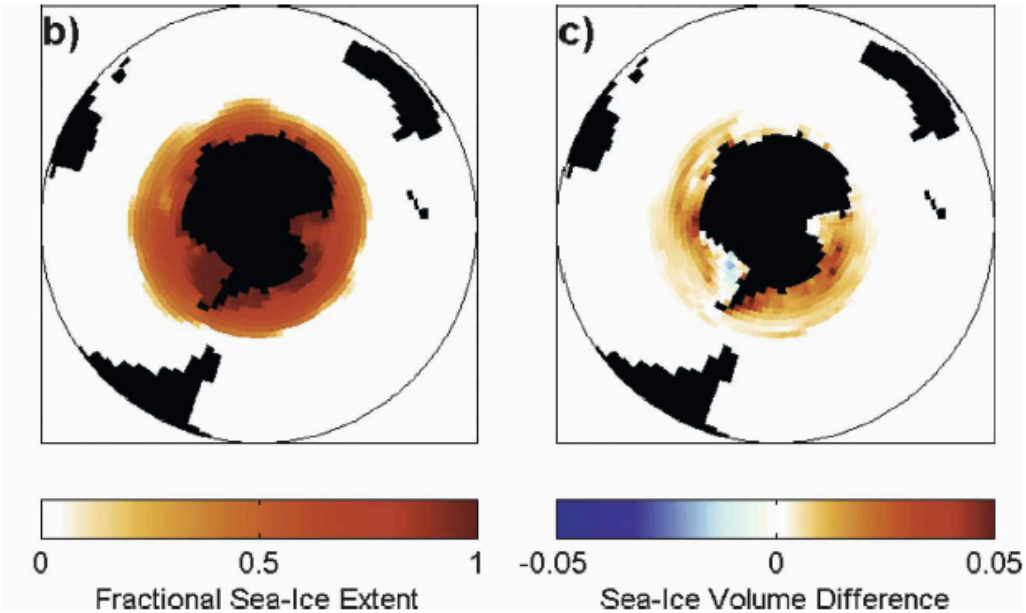
- 0.2 per 50 yrs

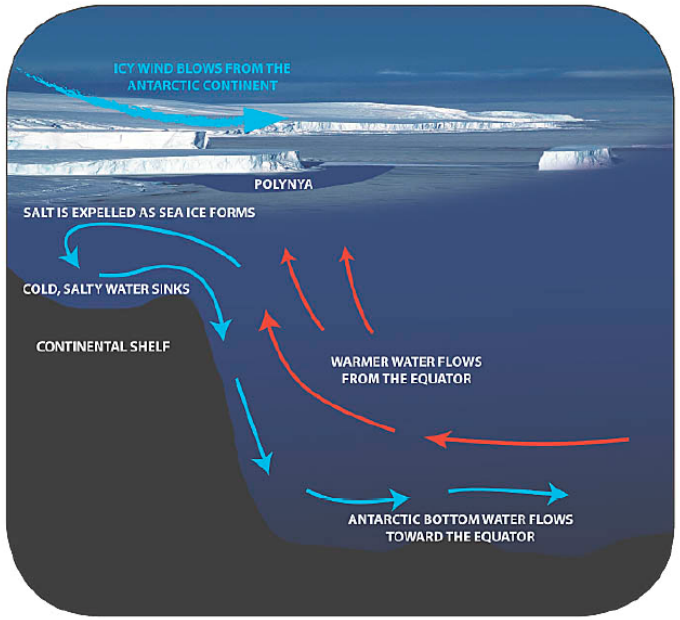
Durack and Wijffels (2010)

Adding FW anomalies also has a cooling effect

CTRL sea-ice

FW+ minus CTRL



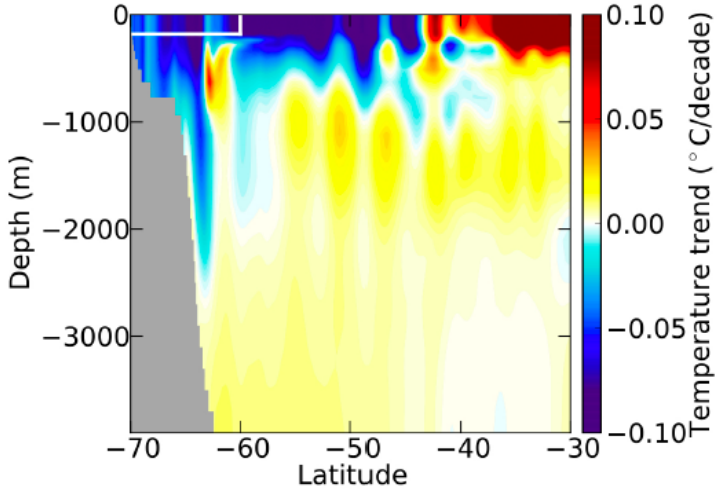


Aiken and England (2008)

See also:

Swart and Fyfe (2013)

Bintanja et al. (2013)

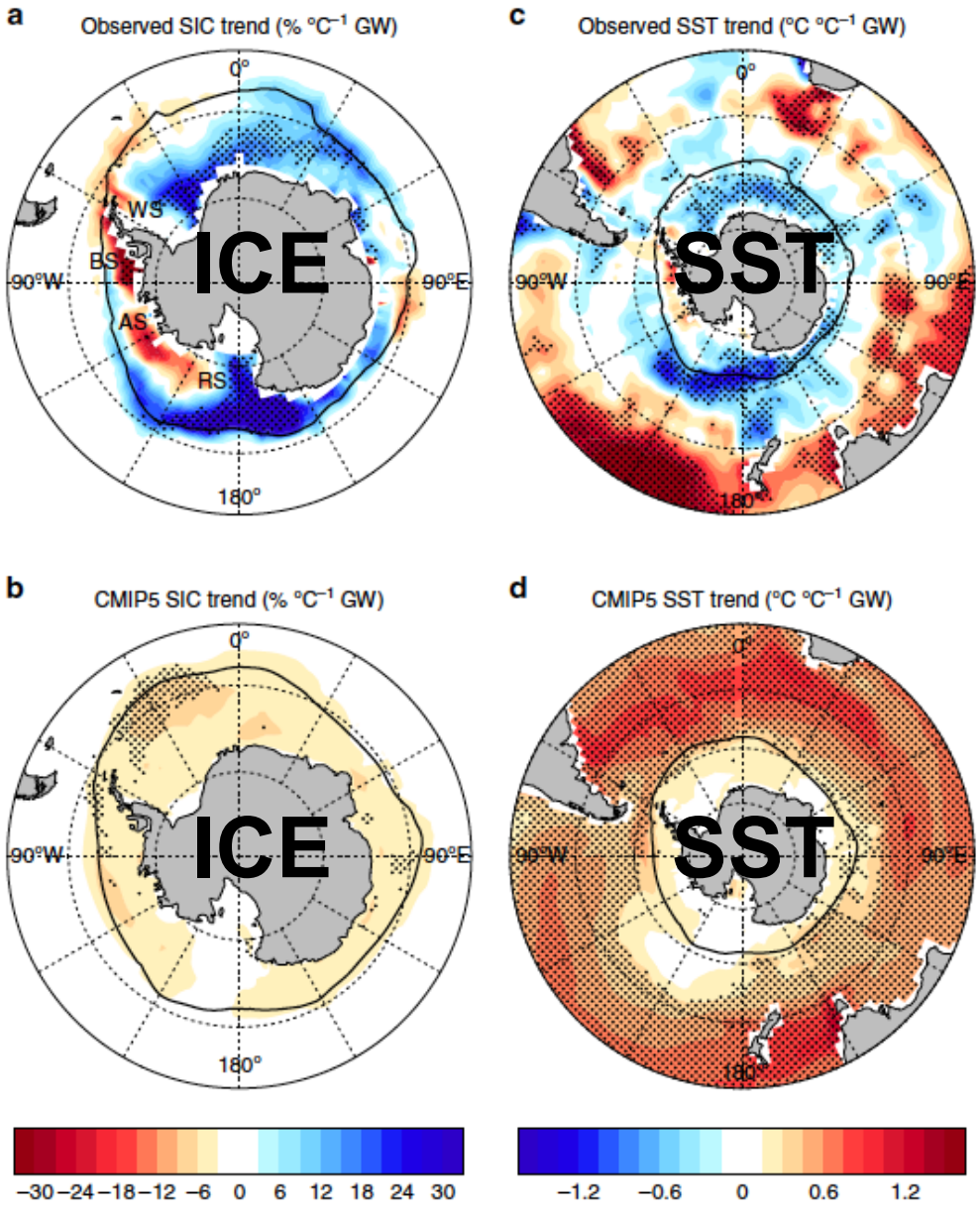


Morrison et al. (2013)

So why don't models capture this transient cooling?

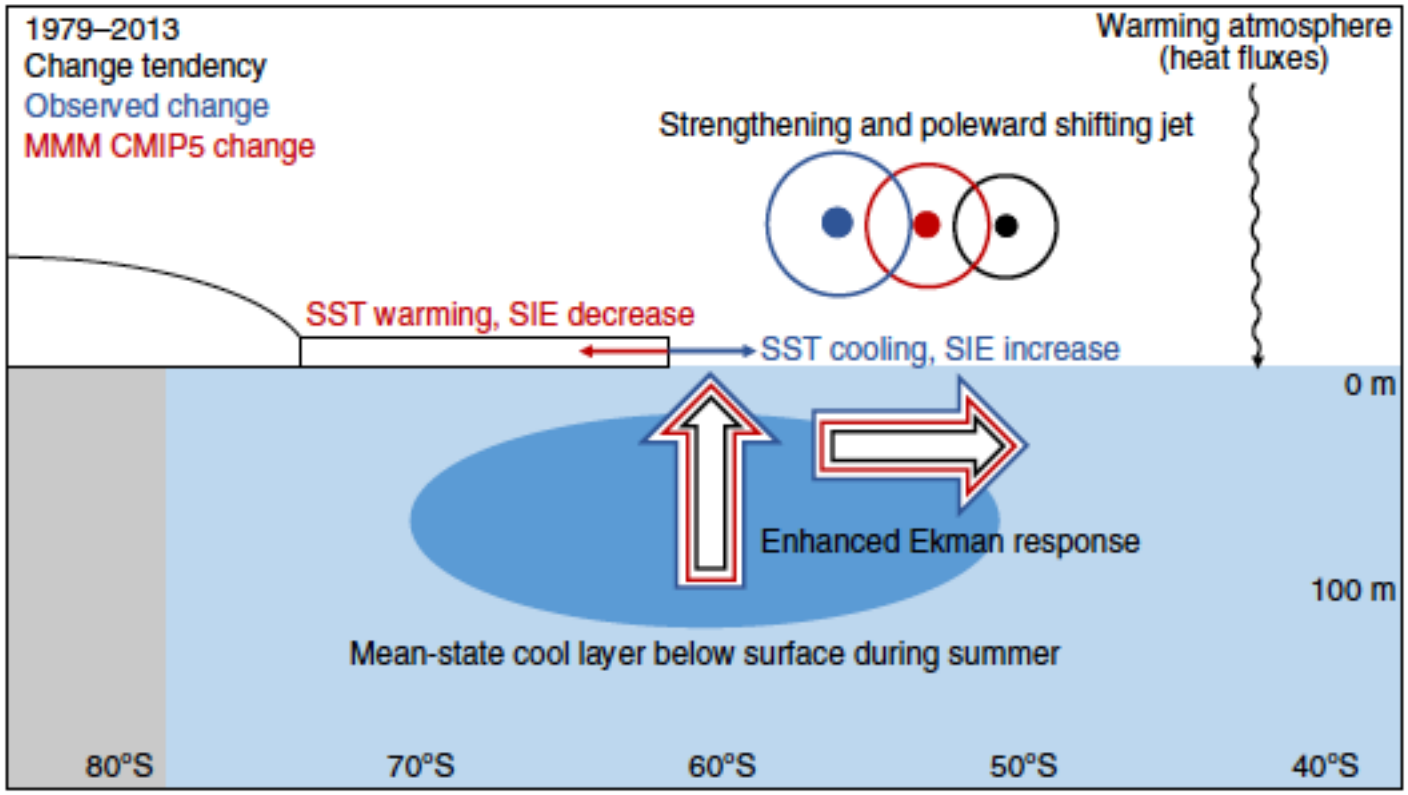
OBS

MMM



So why don't models capture this transient cooling?

Purich et al. (2016)



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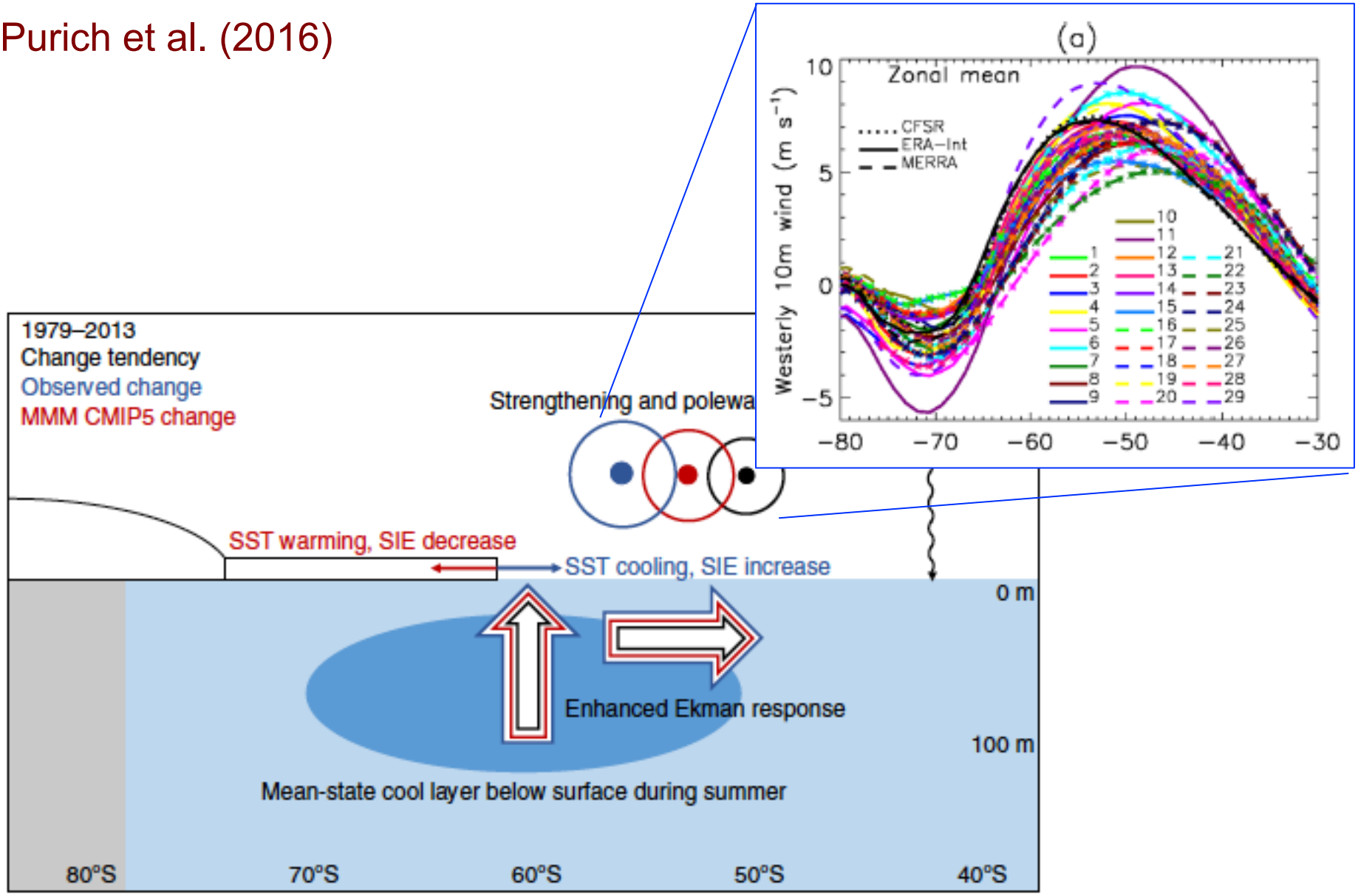

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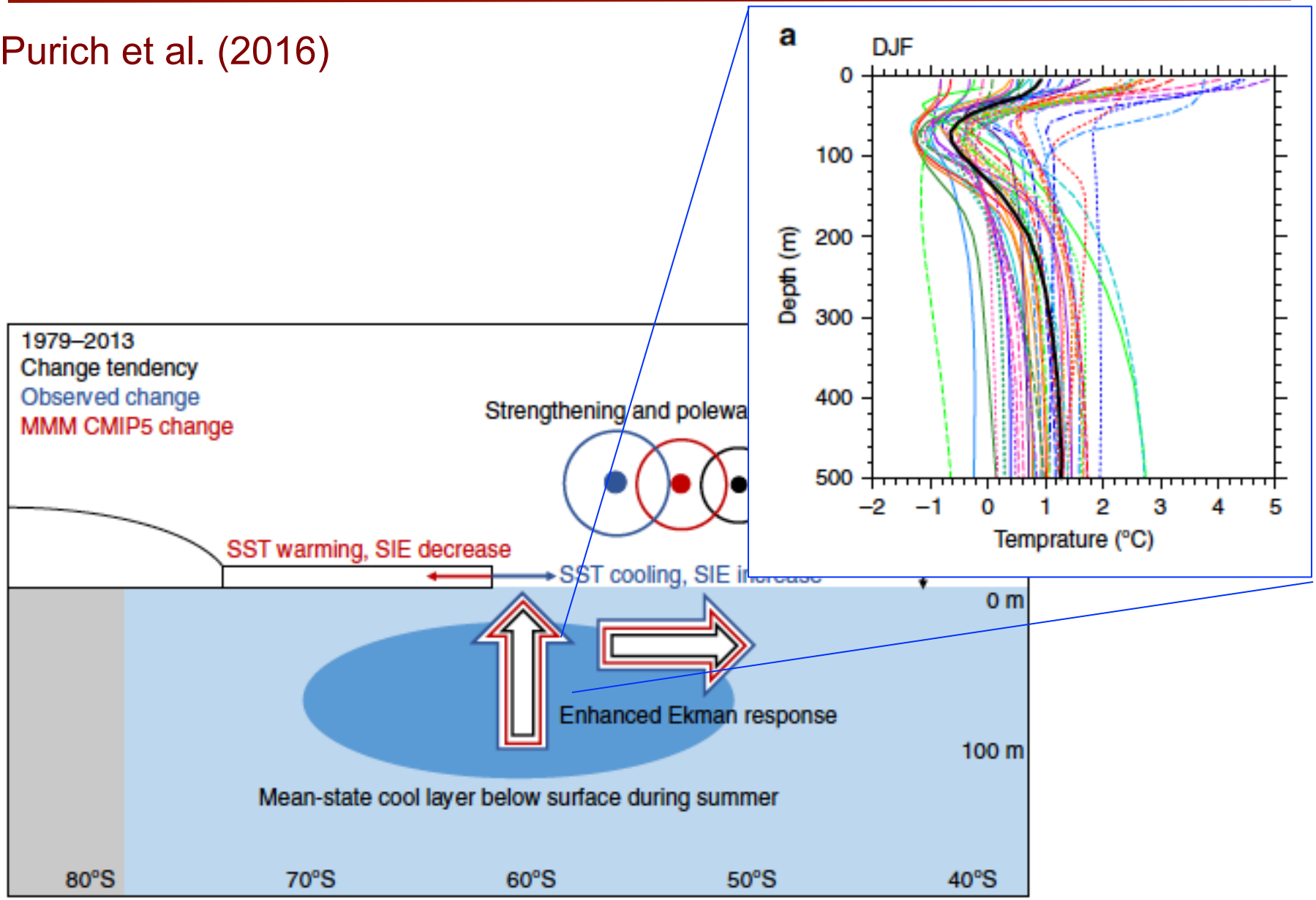
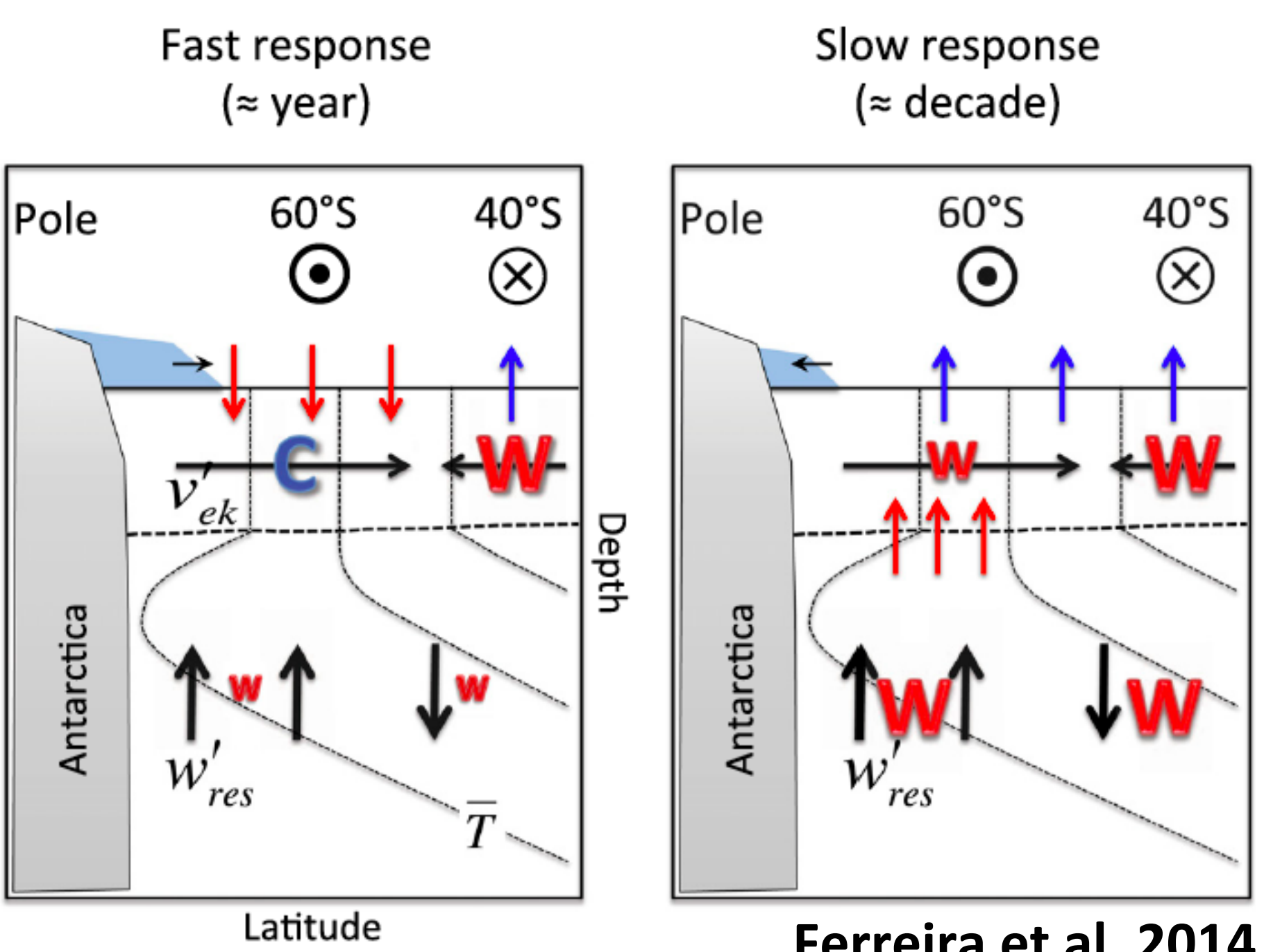




Ferreira et al. 2014

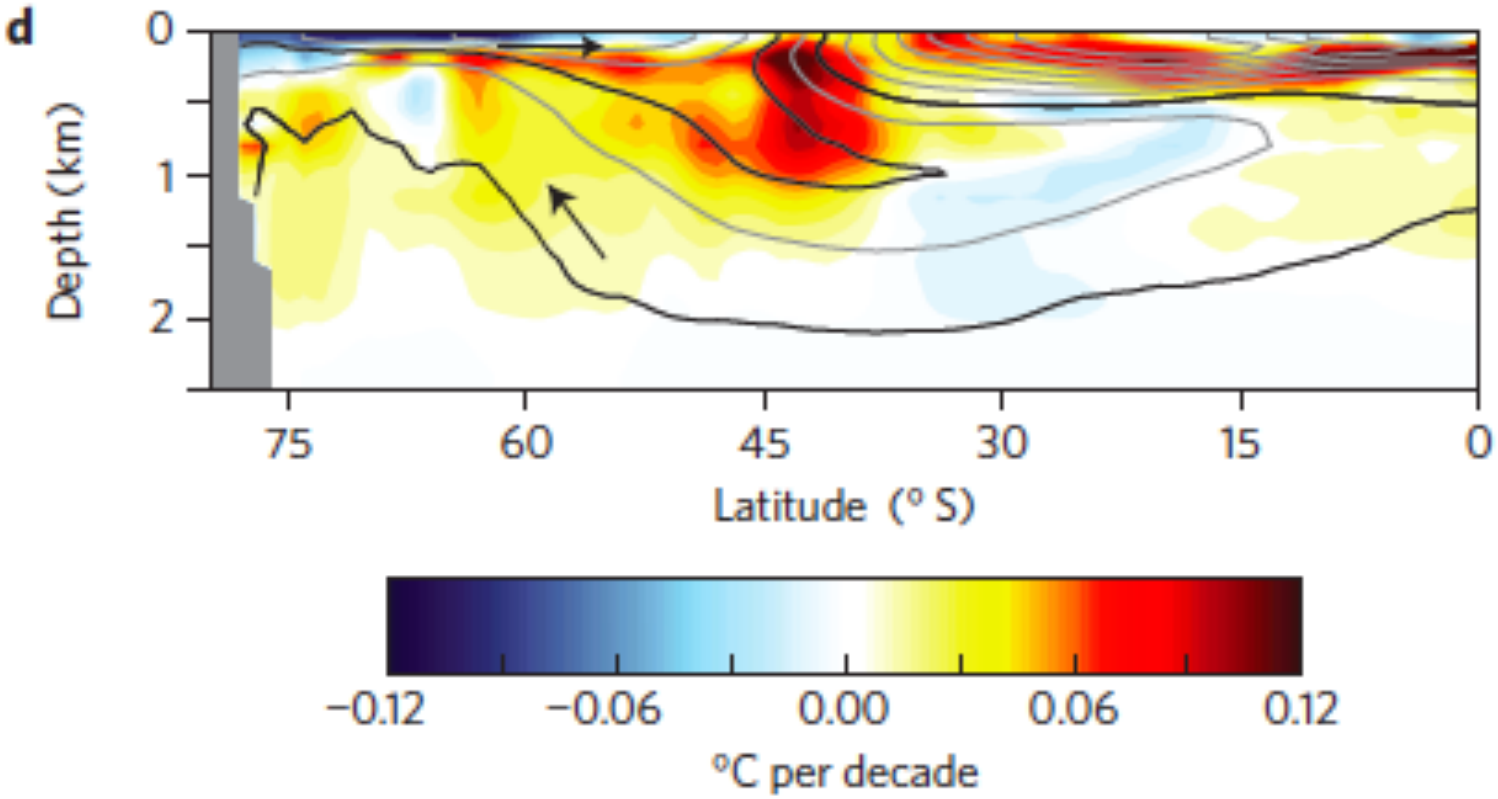
nature geoscience

ARTICLES

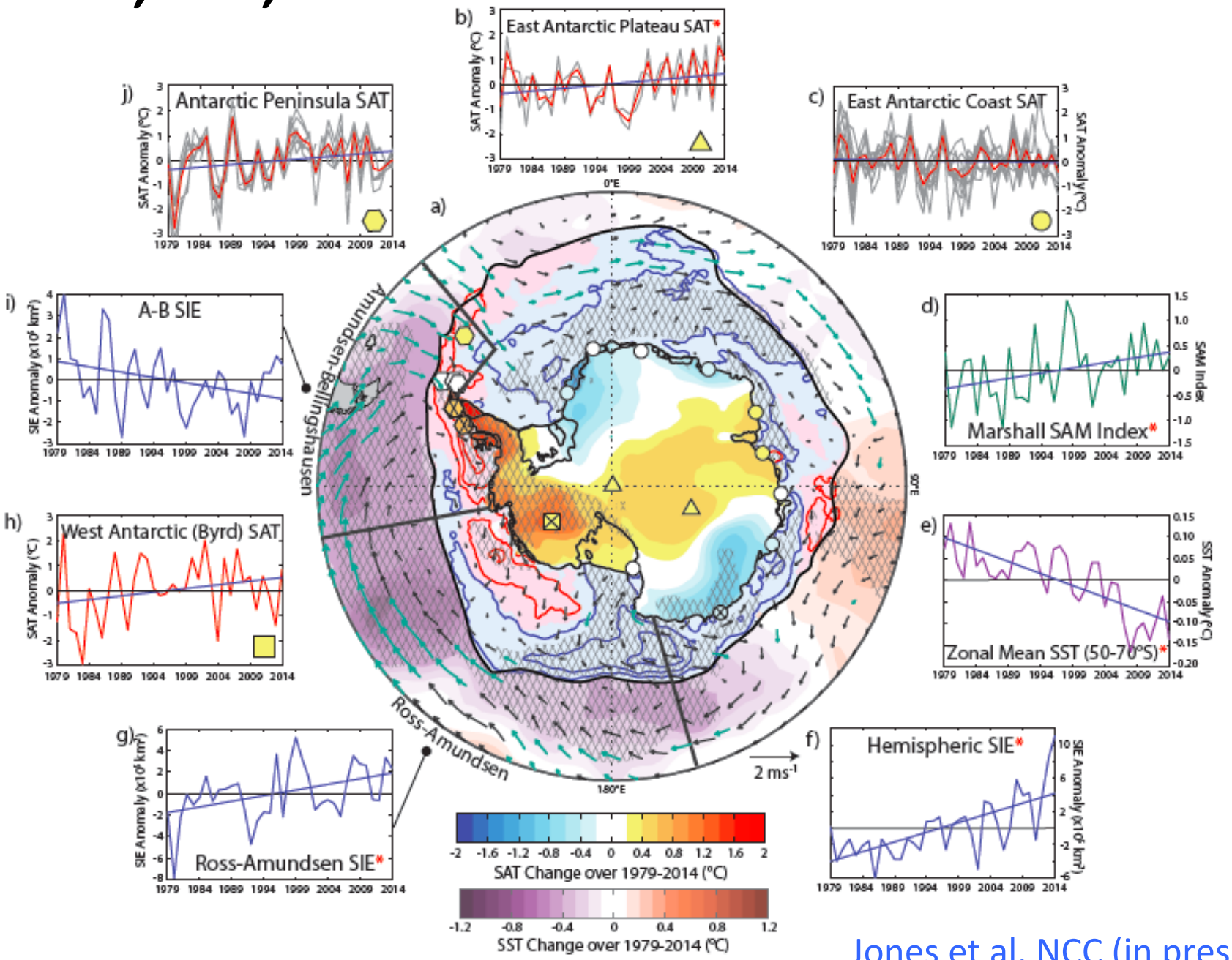
PUBLISHED ONLINE: 30 MAY 2016 | DOI: 10.1038/NGEO2731

Southern Ocean warming delayed by circumpolar upwelling and equatorward transport

Kyle C. Armour[1]*, John Marshall[2], Jeffery R. Scott[2,3], Aaron Donohoe[4] and Emily R. Newsom[5]

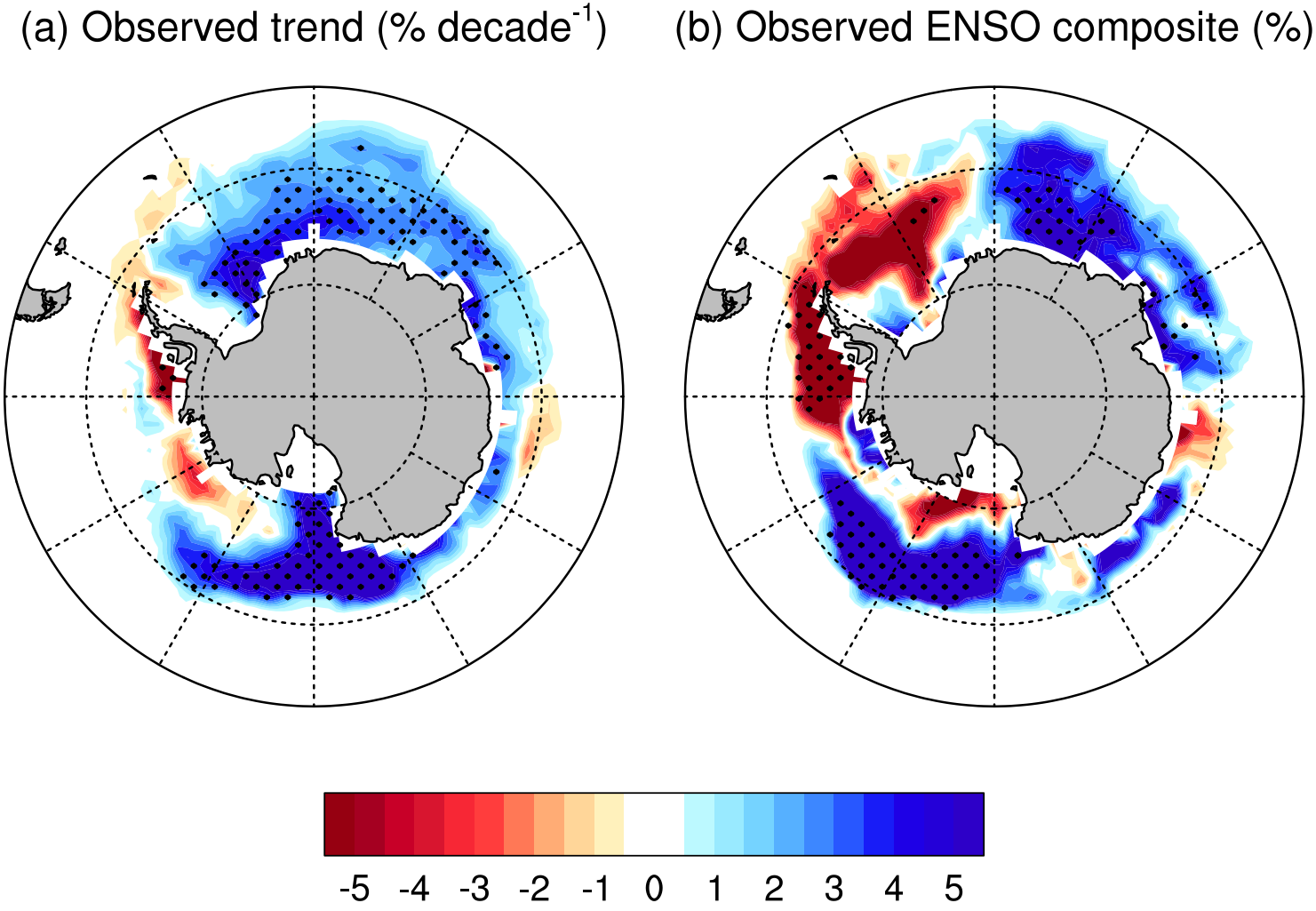


SST, SAT, wind and sea-ice trends 1979-2014



Jones et al. NCC (in press)

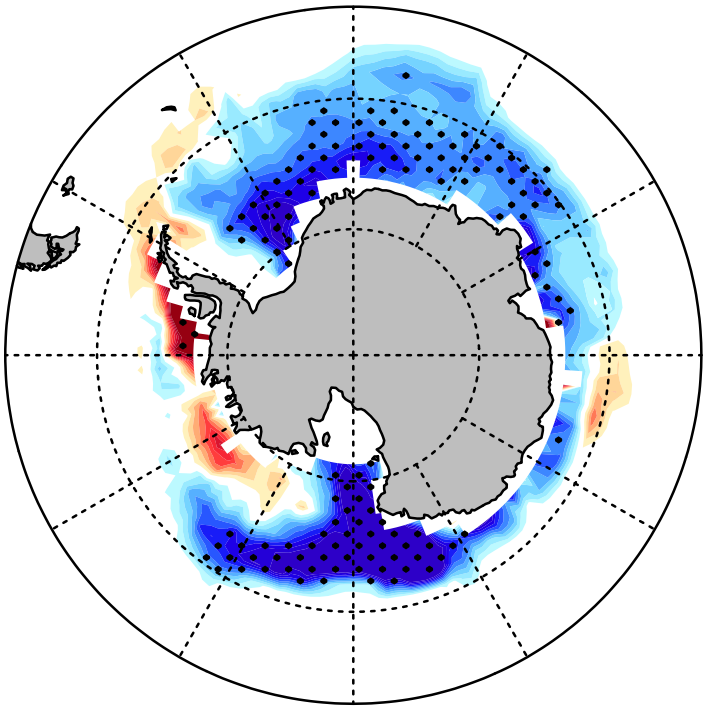
Variability is also playing a significant role….

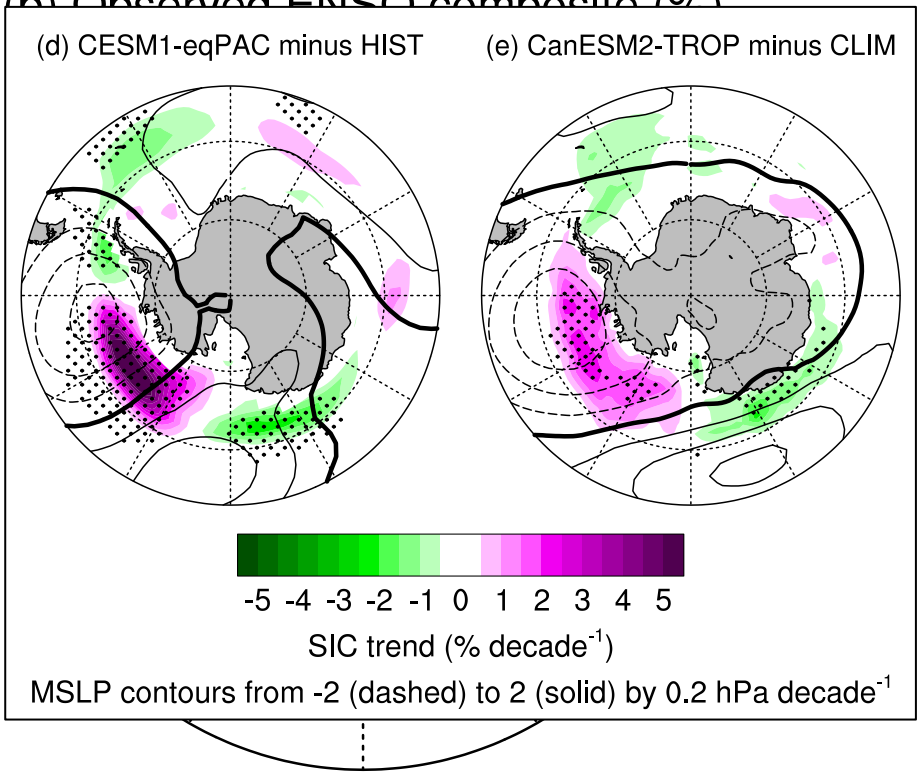


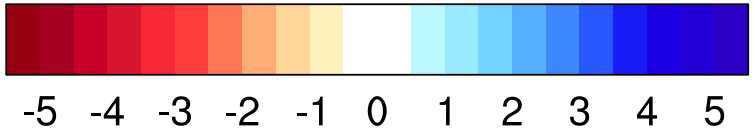
Purich et al. (2016)

Variability is also playing a significant role….

Pacemaker experiments







Purich et al. (2016)

Conclusions

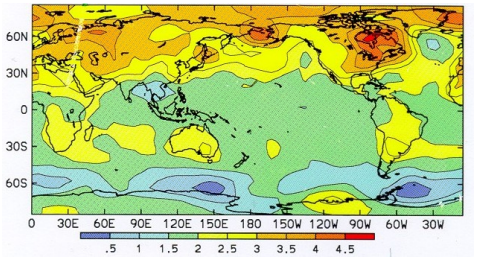
- Interhemispheric asymmetry in SAT response to GHG⇧ is progressing as predicted

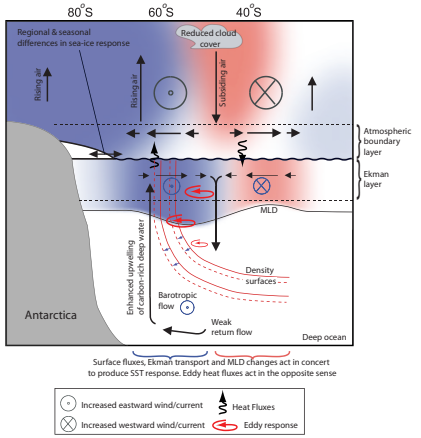
- Along with deep mixed layers north of the ACC, the Southern Annular Mode has made a major contribution to recent high-latitude cooling

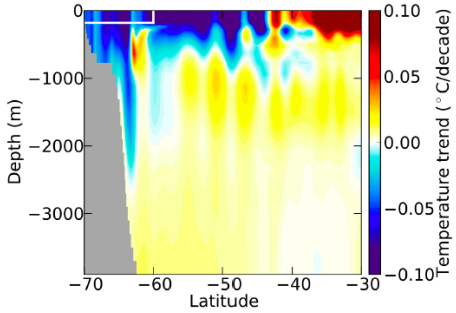
- In addition: warming and/or freshening of the surface Southern Ocean also produces cooling. This occurs due to a reduction of open ocean convection and increased stratification.

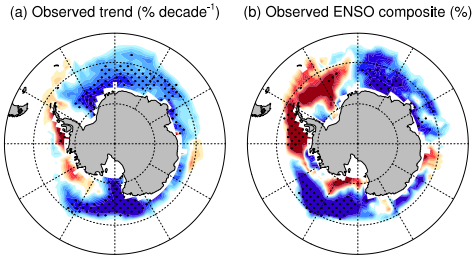
- Interannual – decadal variability is also likely a significant player, via the IPO / ENSO / Atlantic

- ?? Why is the fast time-scale response persisting so long ??



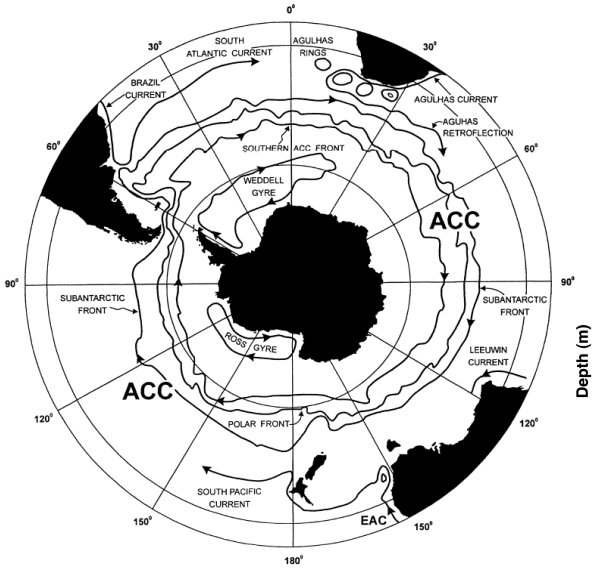


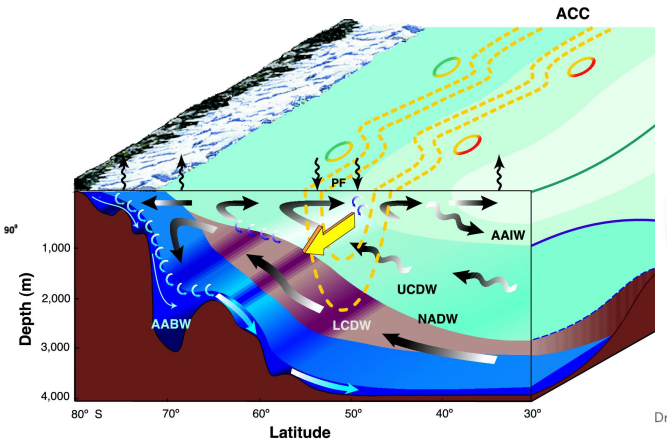


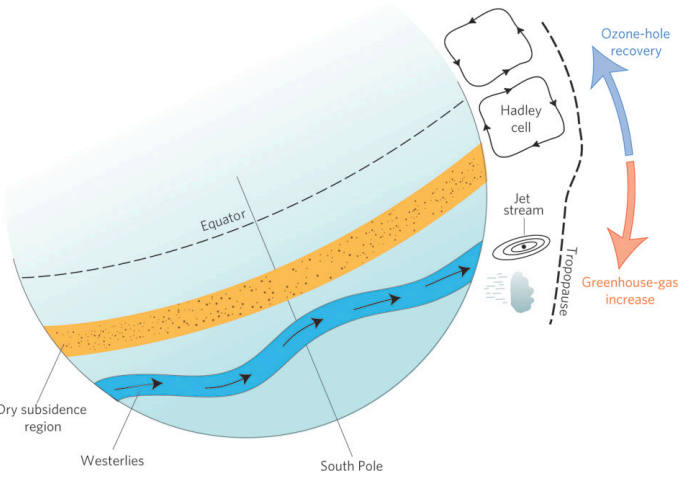


Imprint of the Southern Annular Mode on the coupled ocean-atmosphere-ice system

Matthew England
UNSW Sydney Australia







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