Fast and Slow Response of Sea ice and the Southern Ocean to Ozone Depletion

by Cecilia Bitz

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and

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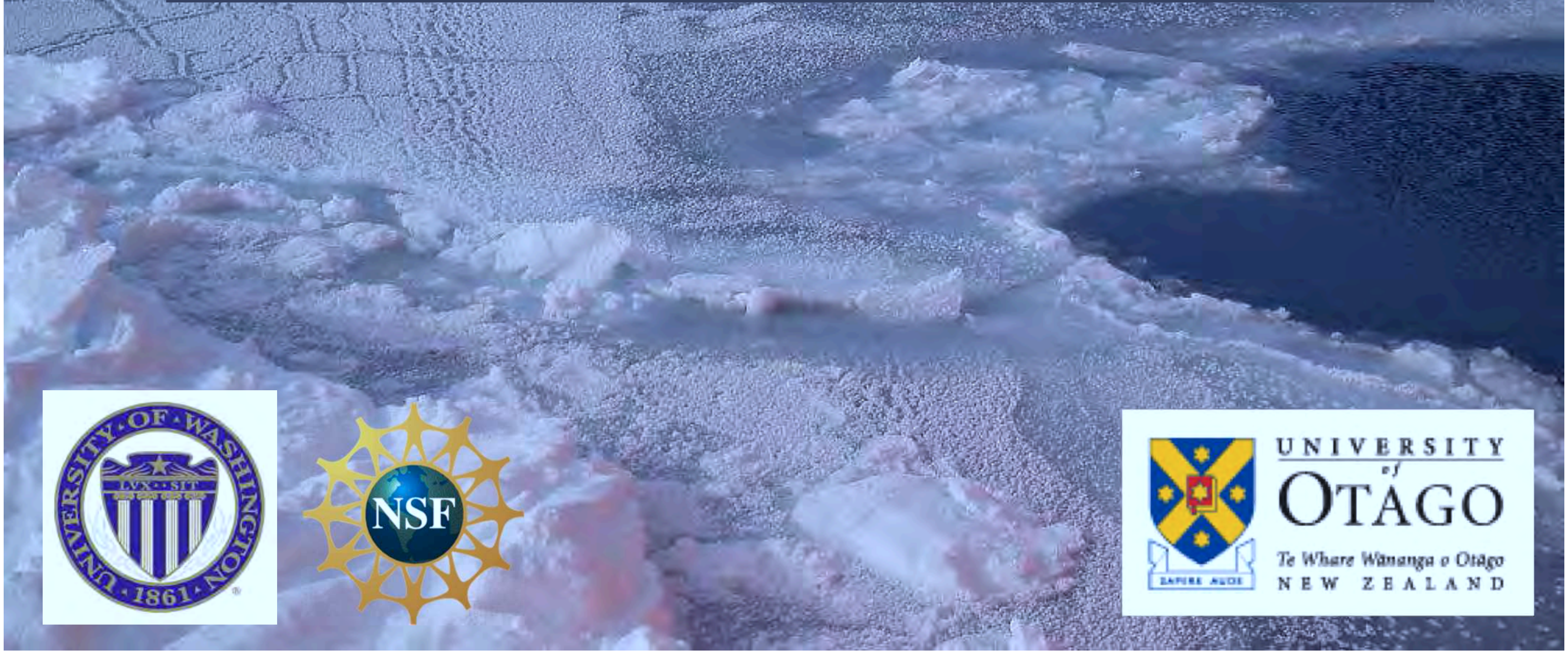
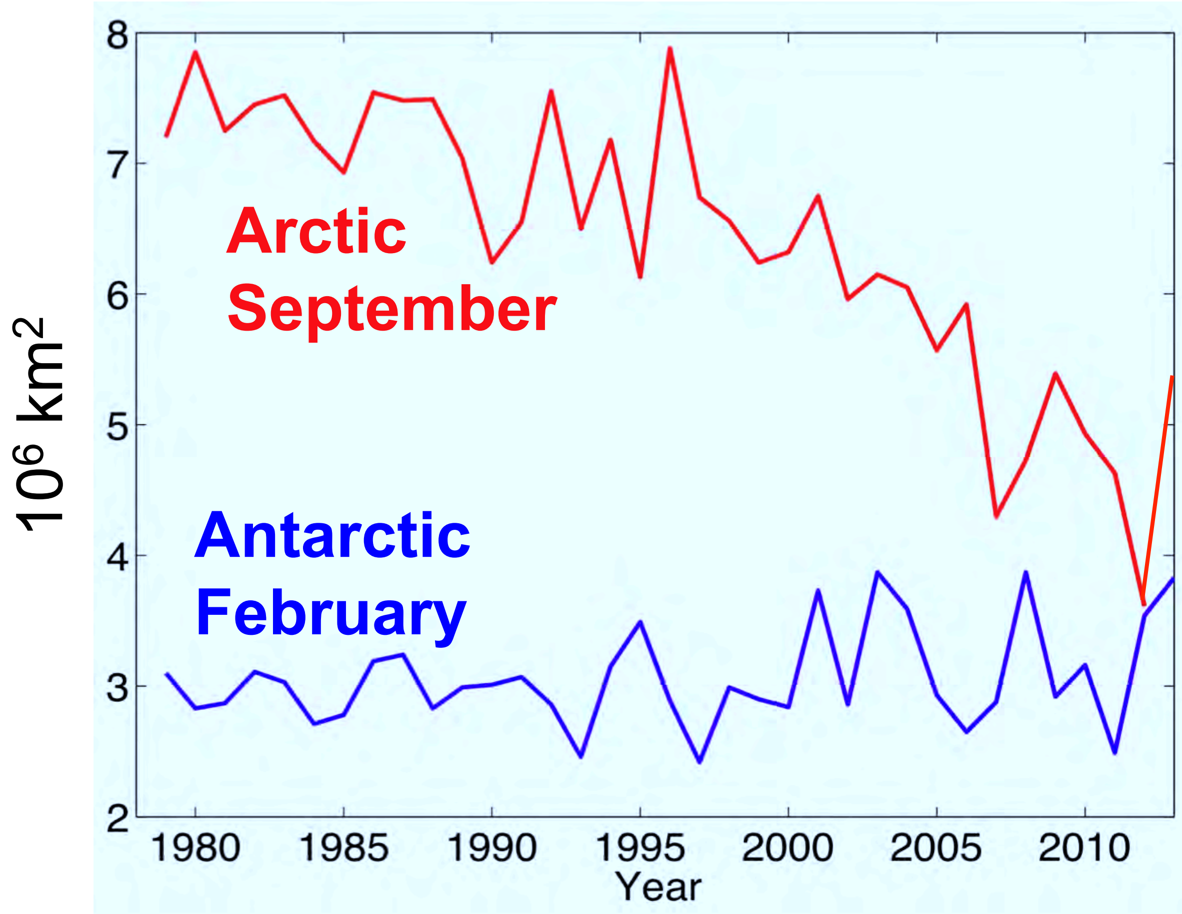
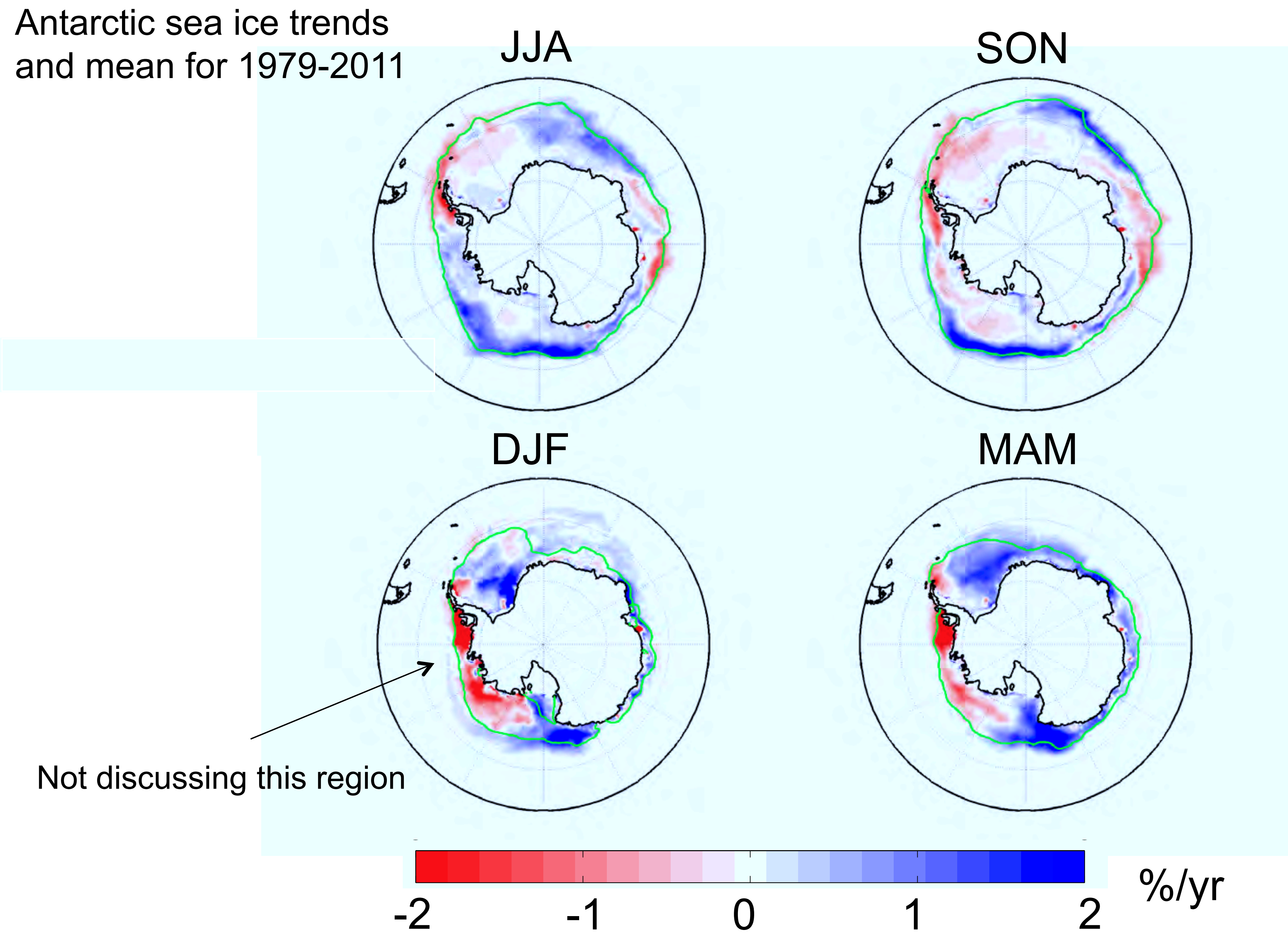


Annual Minimum Sea ice extent 1979-2013



Data from in passive microwave satellite


Antarctic sea ice trends
and mean for 1979-2011
JJA
SON
DJF
MAM
Not discussing this region
-2
-1
0
1
2
%/yr

Antarctic February Sea Ice Area
CMIP5 Models RCP4.5

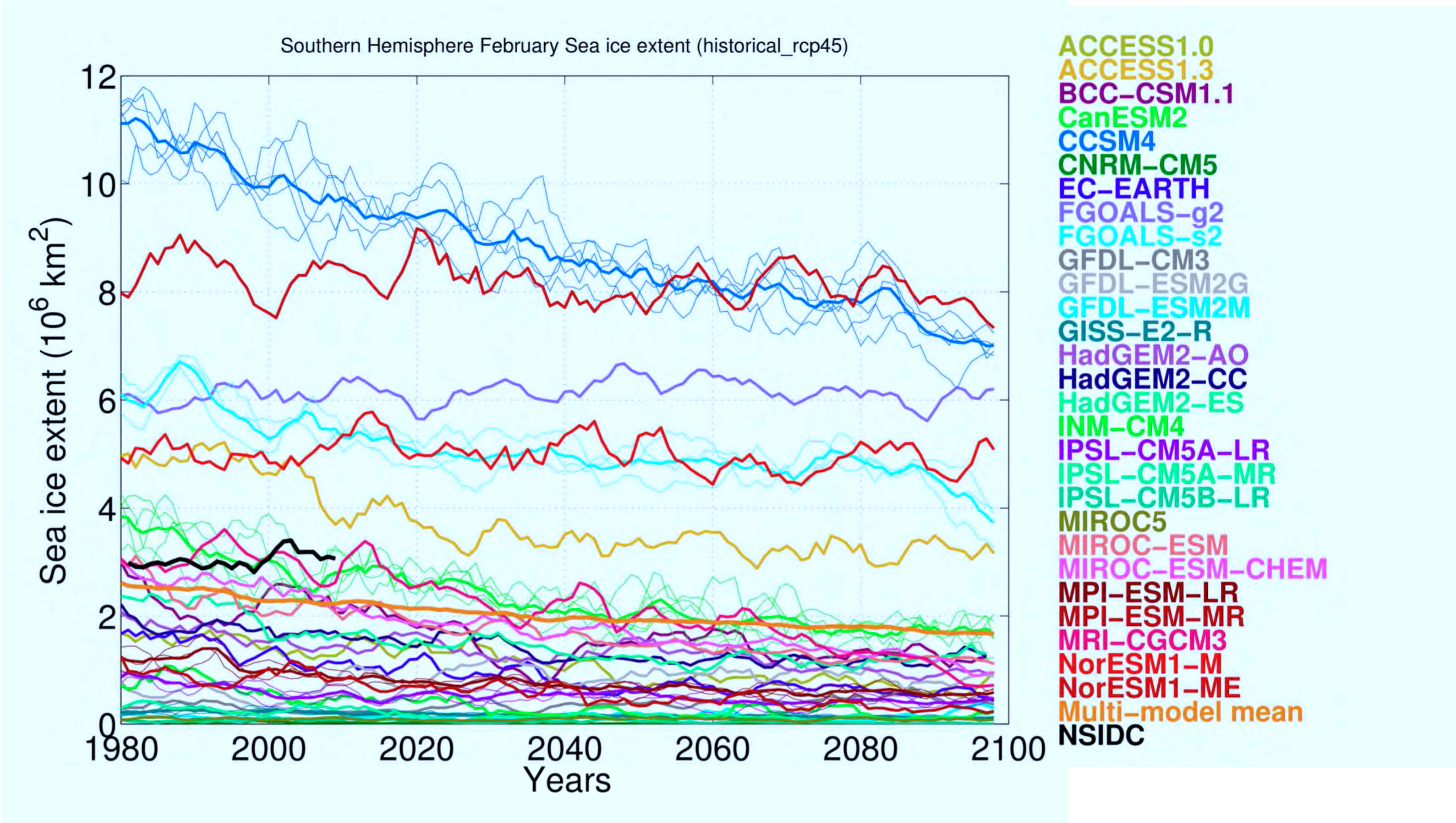
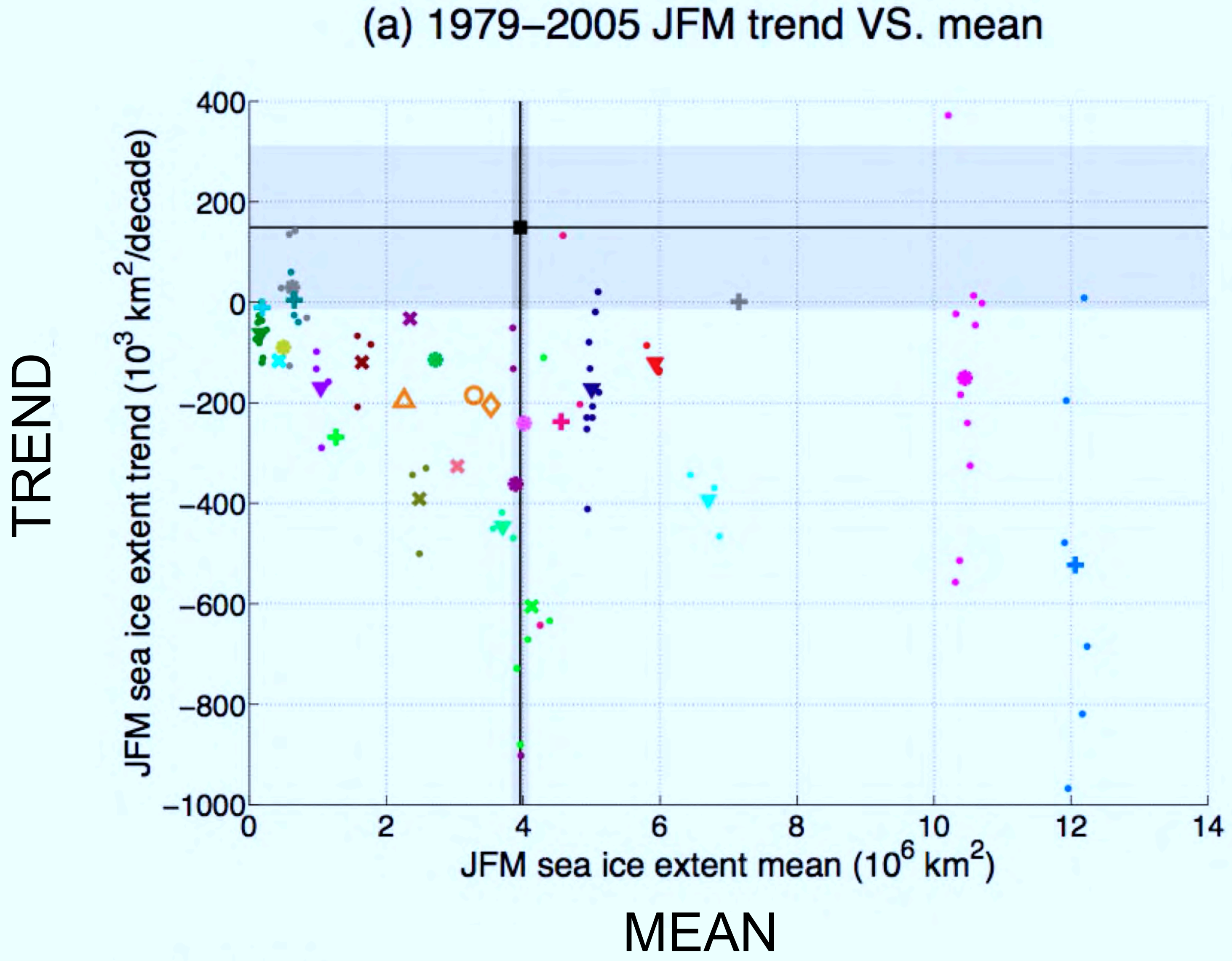


Figure by F Massonnet

Antarctic Extent in CMIP5 Models



Zunz et al(2013)

Theories for sea ice expansion outside of the Bellingshausen and Amundsen Sea

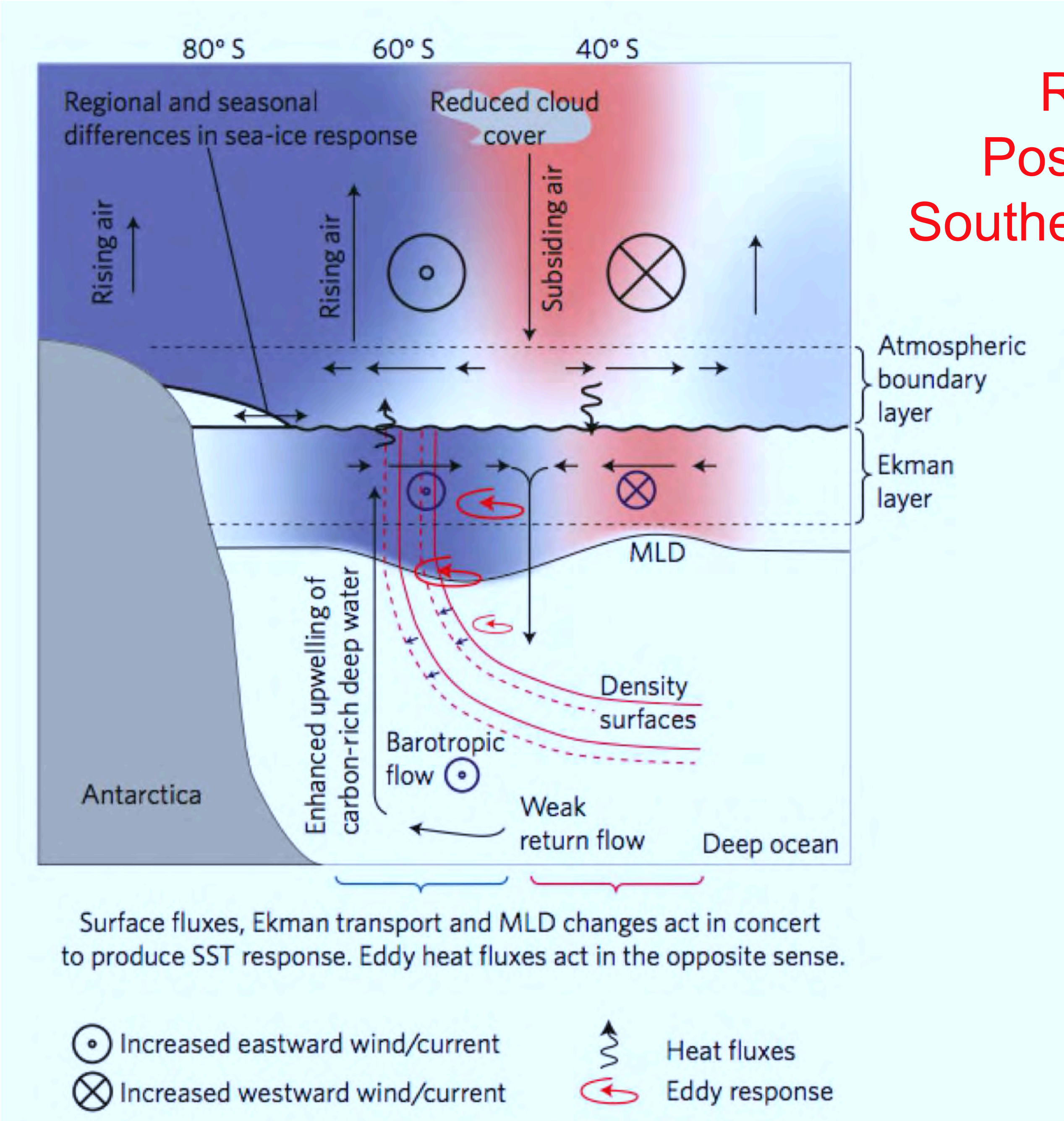
1) Winds trends from Southern Annular Mode (SAM) trends (driven by ozone primarily), direct effect on sea ice and ocean

I think this one is right!!!

2) Freshwater trends (ice bergs, ice sheet/shelf melt, precipitation, sea ice melt/freeze), may be indirect effect of winds

But I’m going to explain why (1) is wrong

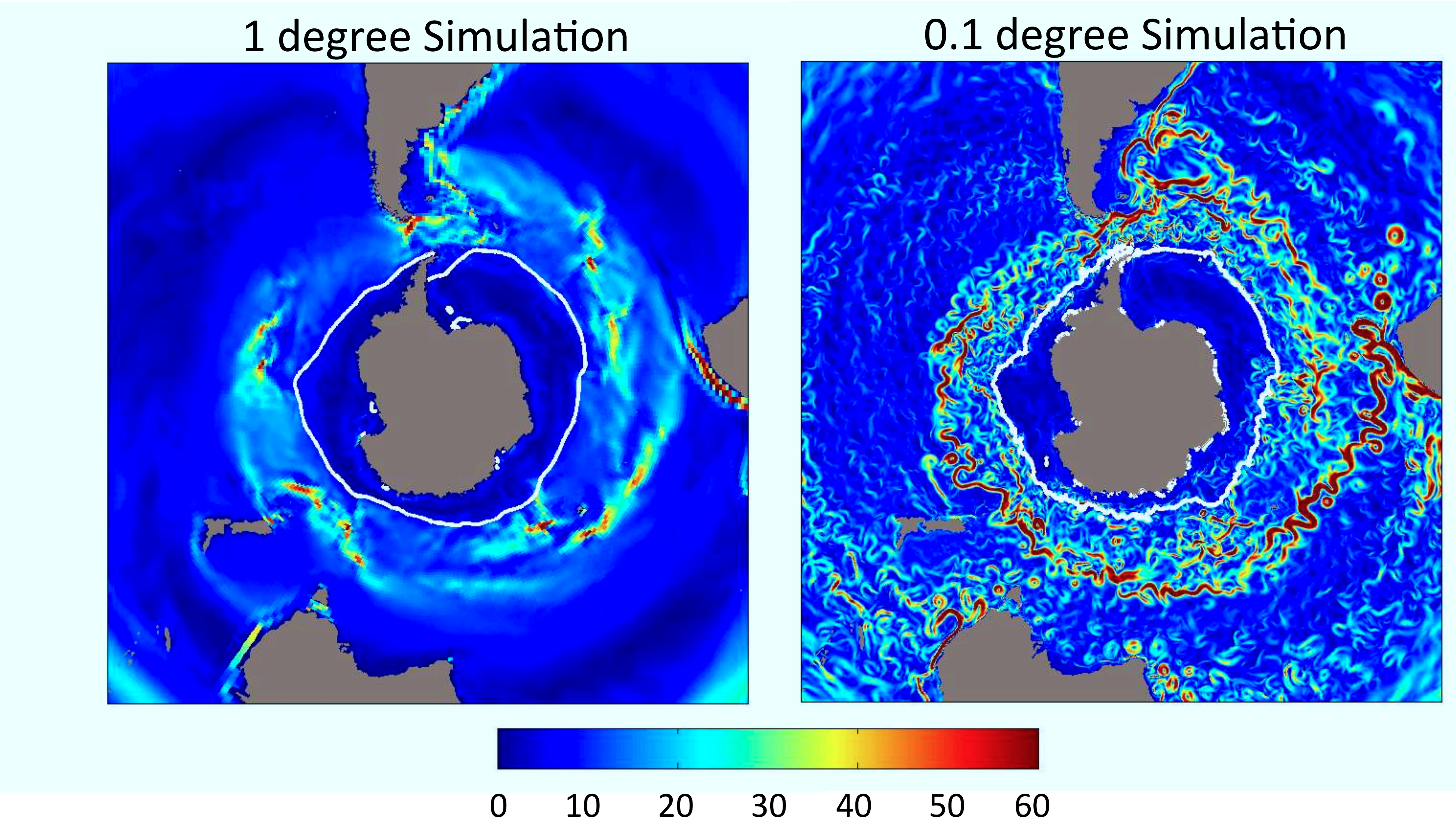
Response to Positive Phase of Southern Annular Mode



Colors show **fast response** warming/cooling
But there are other factors that dominate on slower timescales and change the response eventually

Thompson et al (2011)

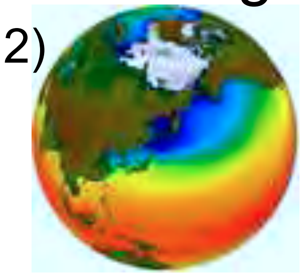
Simulated Surface Currents and Sea Ice Extent Around Antarctica



Current Speed in cm/s for randomly chosen October

Animations of these runs are at http://www.atmos.uw.edu/~bitz//bothmovies/bothmovies.html

Simulations using Community Climate System Model Version 3.5 with Ozone Anomaly from AC&C/SPARC datasets for CMIP5 to test if CMIP models are failing due to coarse resolution (Bitz and Polvani , 2012)



At two ozone levels:

High Ozone (1940s) or "Normal"

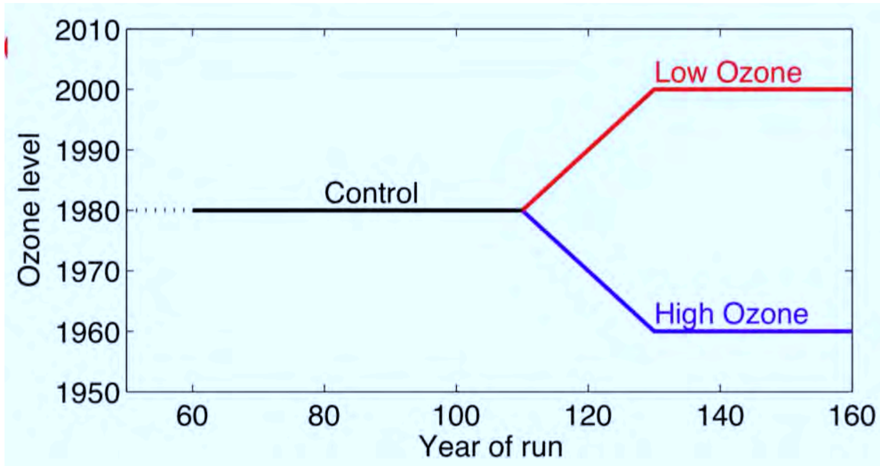
Low Ozone (1990s) or "Most depleted"

At two resolutions:

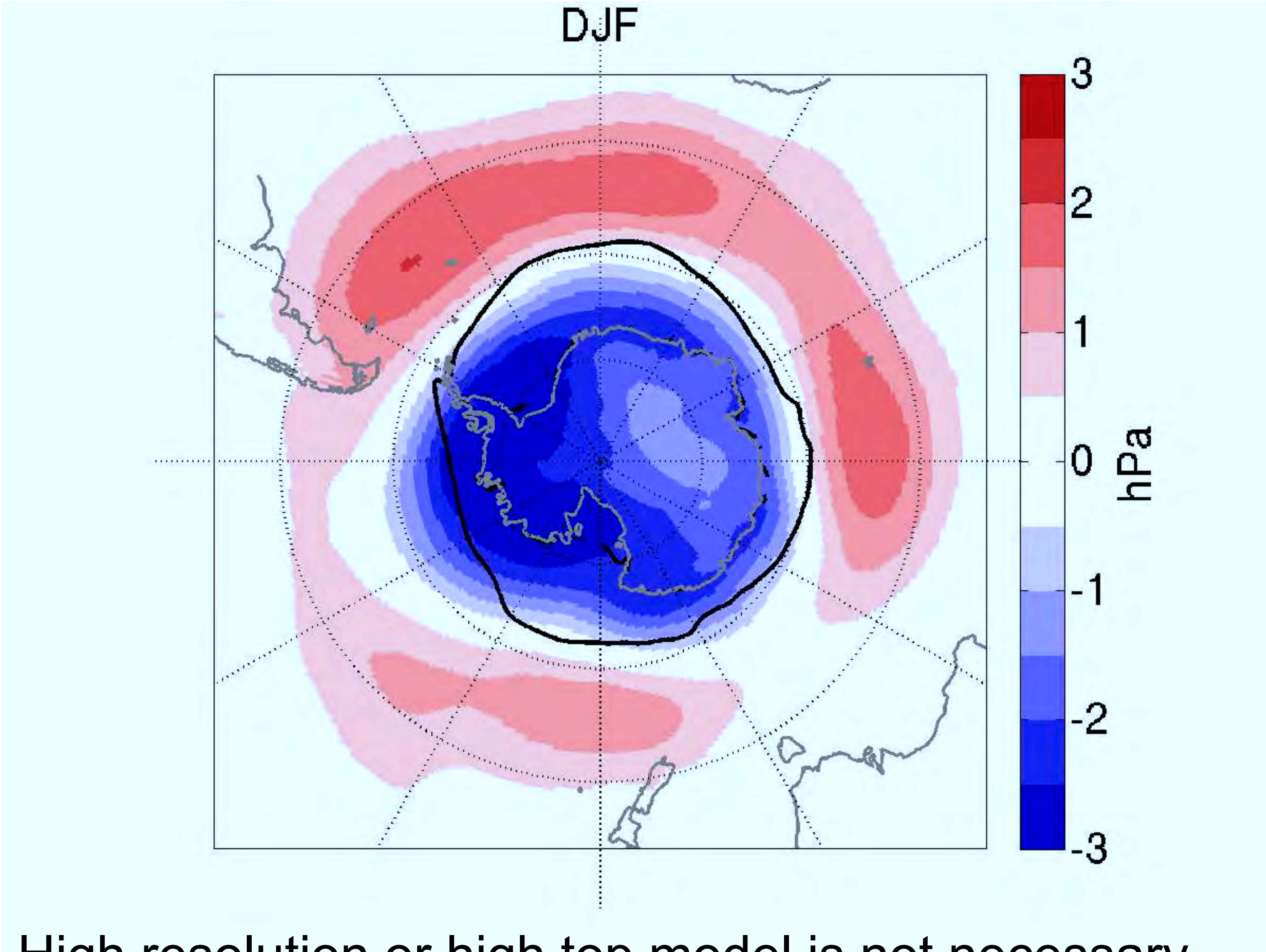
Coarse – 1° ocean and sea ice

Fine – 0.1° ocean and sea i

Four runs in total, each 50 yr long – ramp ozone 20 yr and hold fixed for 30 yr. Results shown are differences of last 30 yr giving the quasi-equilibrated (slow) response

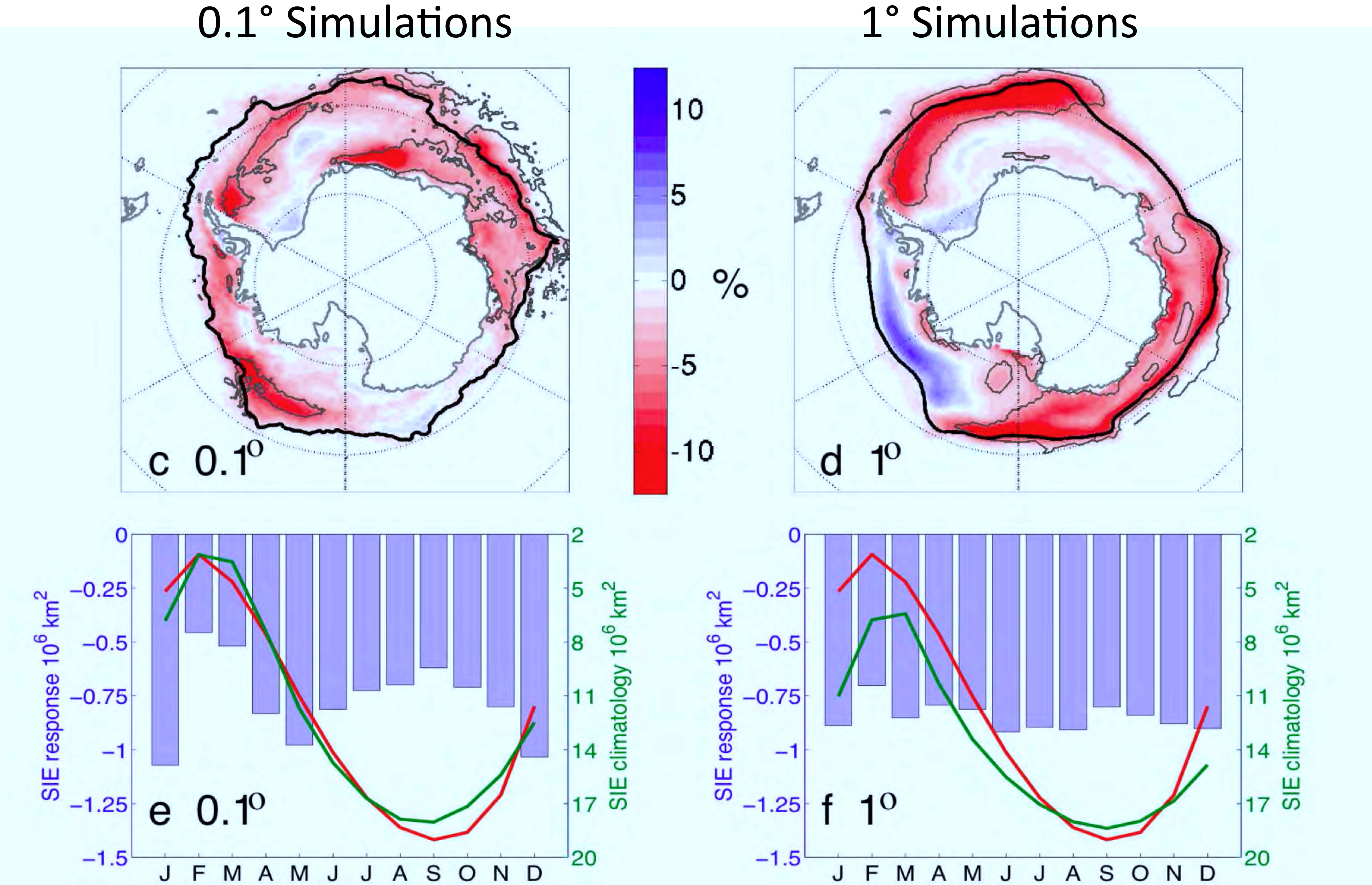


DJF Sea Level Pressure
Response to Depleting Ozone

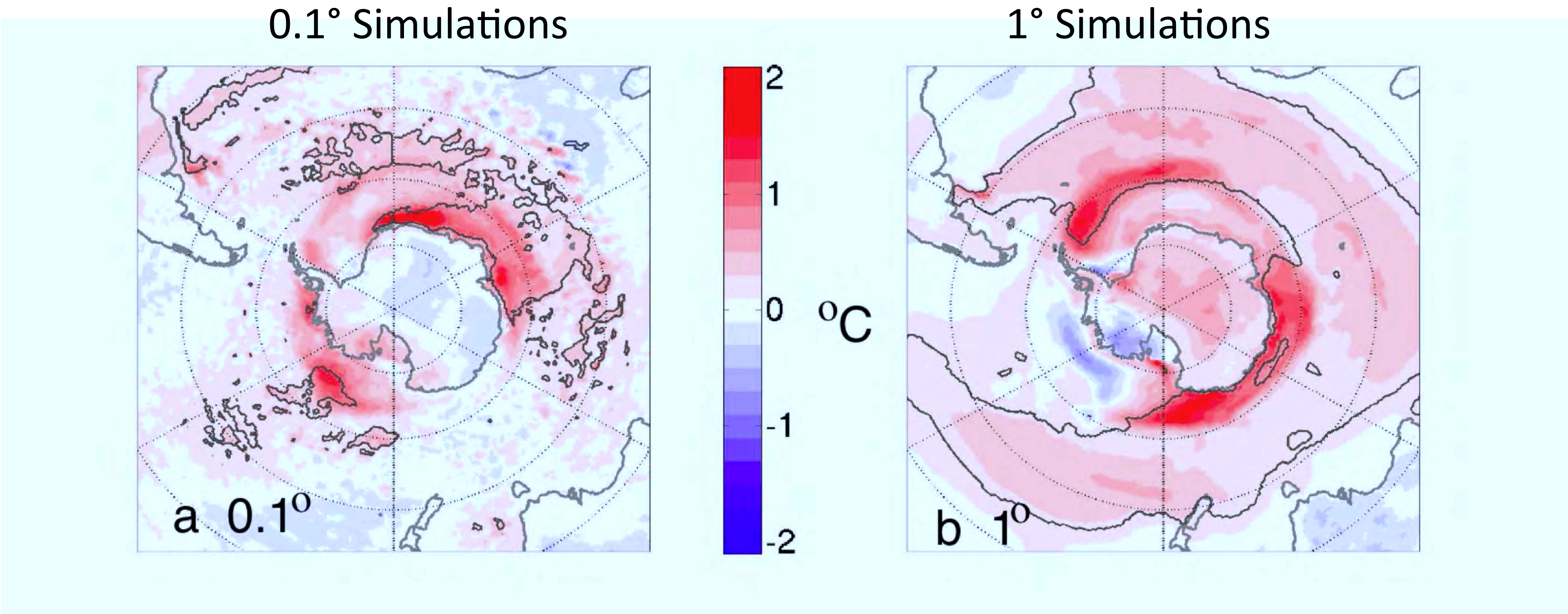


High resolution or high top model is not necessary

Annual Mean Sea Ice Concentration Response to Ozone Loss

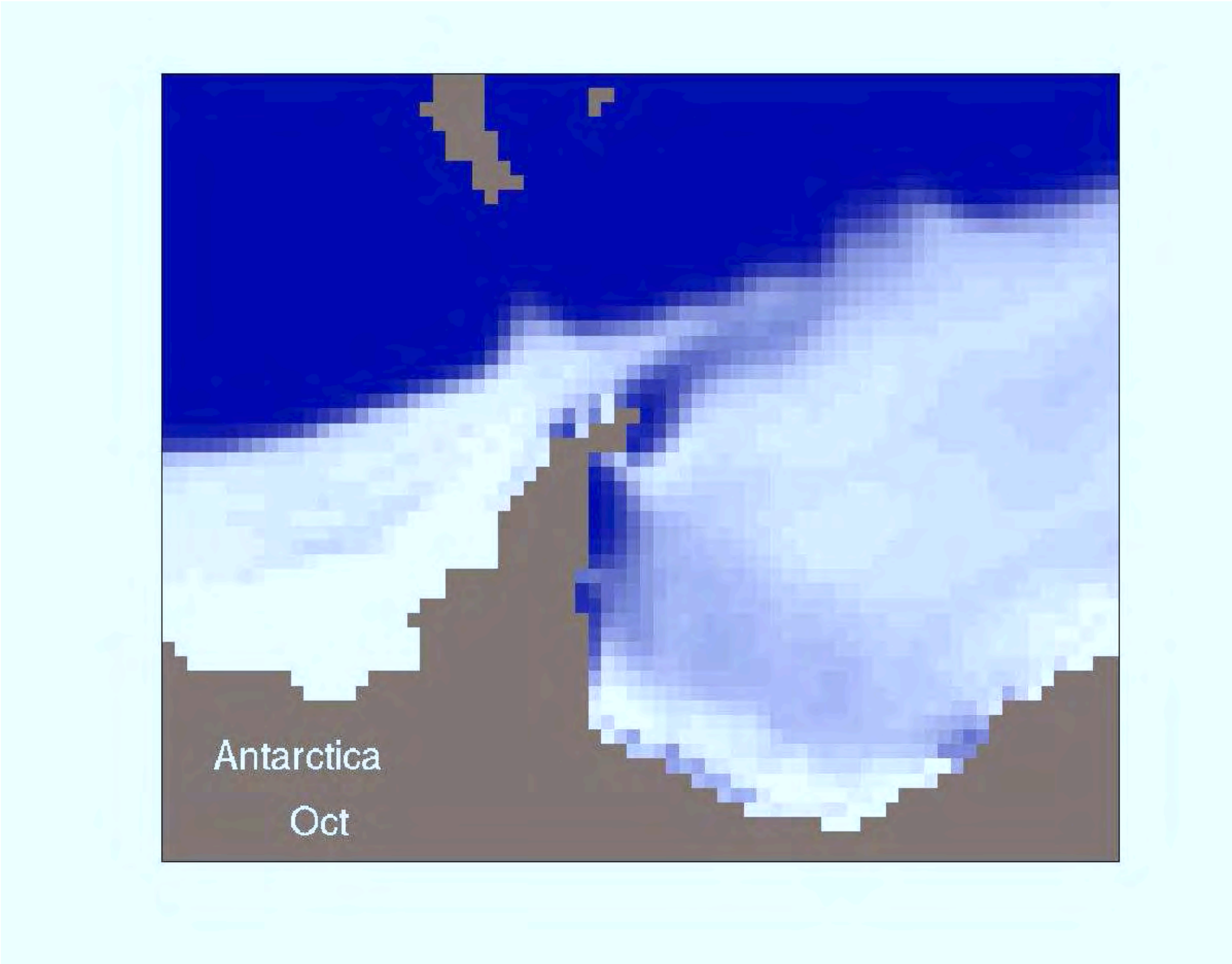


Annual Mean Surface Air Temperature Response to Ozone Loss

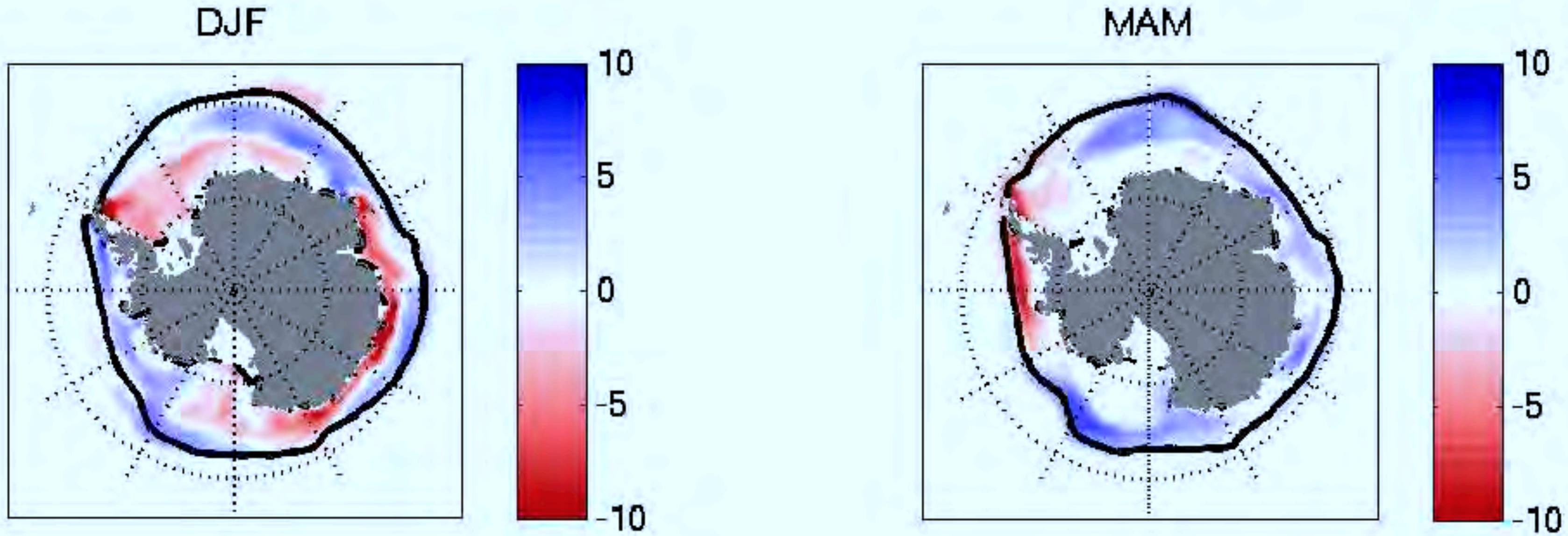


Further results shown are 1° only
(analysis was done at both resolutions)

All further results use the 1° model



Regress sea ice concentration on DJF SAM index in control run

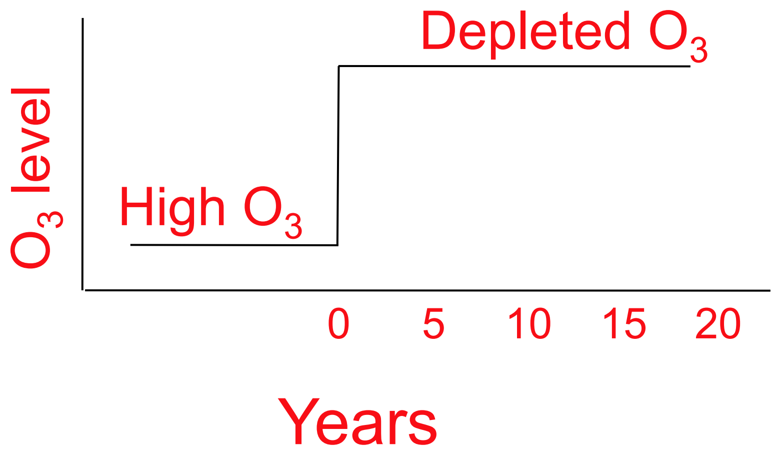


% per one standard deviation change in SAM

This figures proves that the model resembles the observed SAM – sea ice relationship on interannual variability. Sea ice extent increases but area is little changed in DJF because sea ice is transported from near continent towards edge. In MAM, it is cold enough to freeze the gaps that are left near the continent.

Climate Response Function to O_3

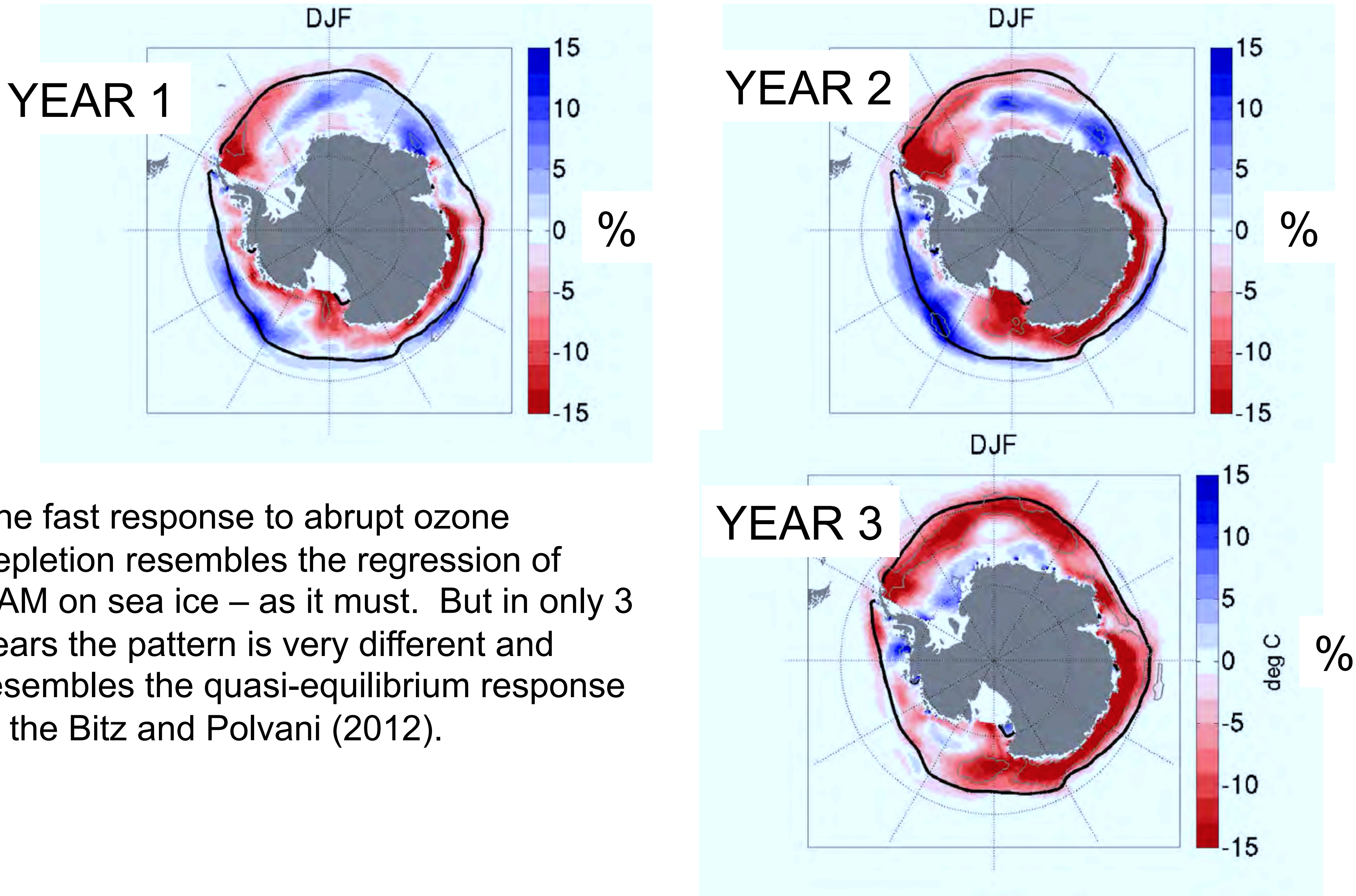
Abruptly deplete O_3 at year zero:



20 ensemble members from 20 different branch points in high O_3 run. Run all for 28 months. Run six for 20 years.

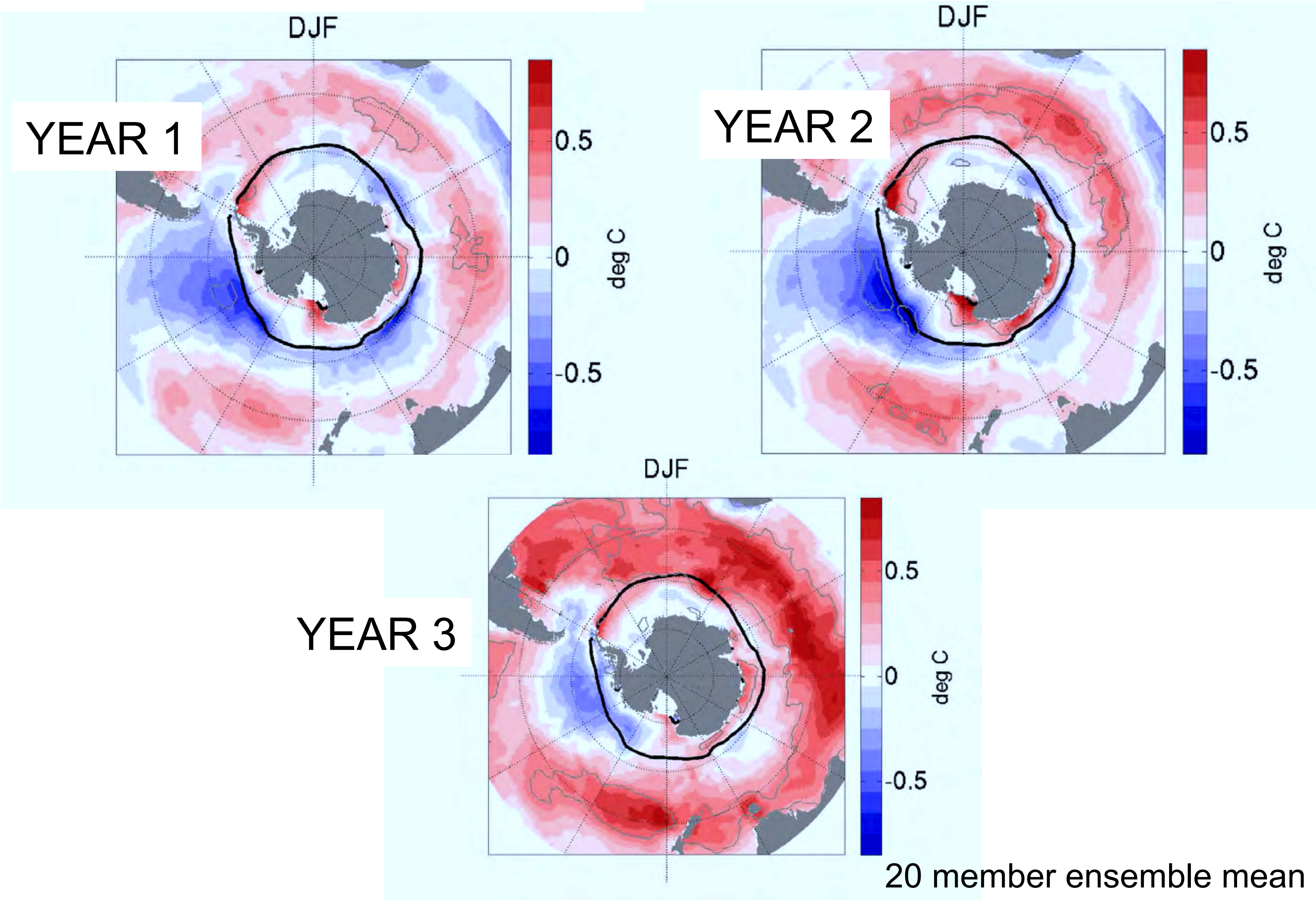
Sea Ice Concentration Response to Abrupt O_3 Depletion

20 member ensemble mean



The fast response to abrupt ozone depletion resembles the regression of SAM on sea ice – as it must. But in only 3 years the pattern is very different and resembles the quasi-equilibrium response in the Bitz and Polvani (2012).

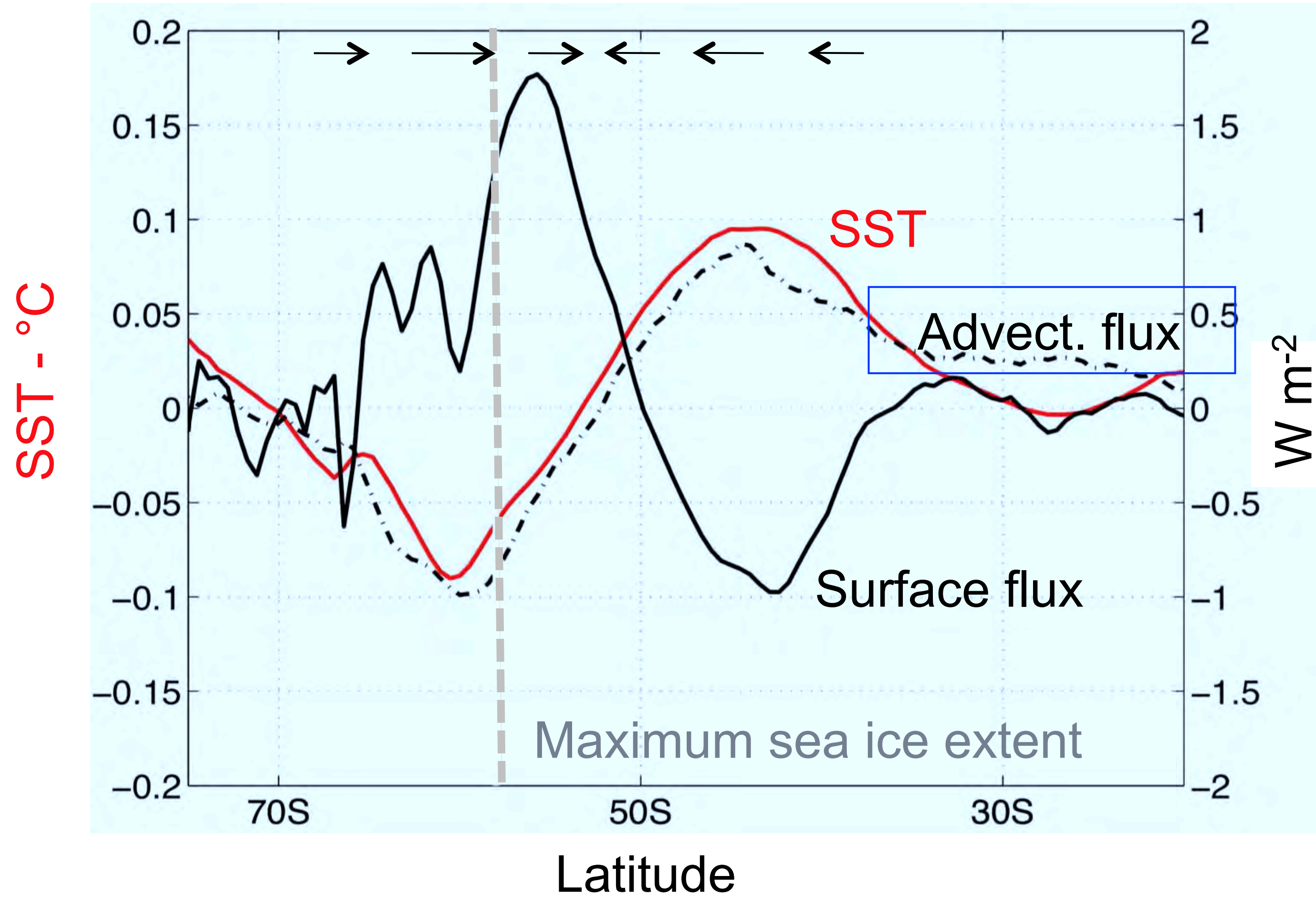
SST Response to Abrupt O_3 Depletion



20 member ensemble mean

SST and Mixed Layer Heating Terms

Fast response* to abrupt ozone depletion



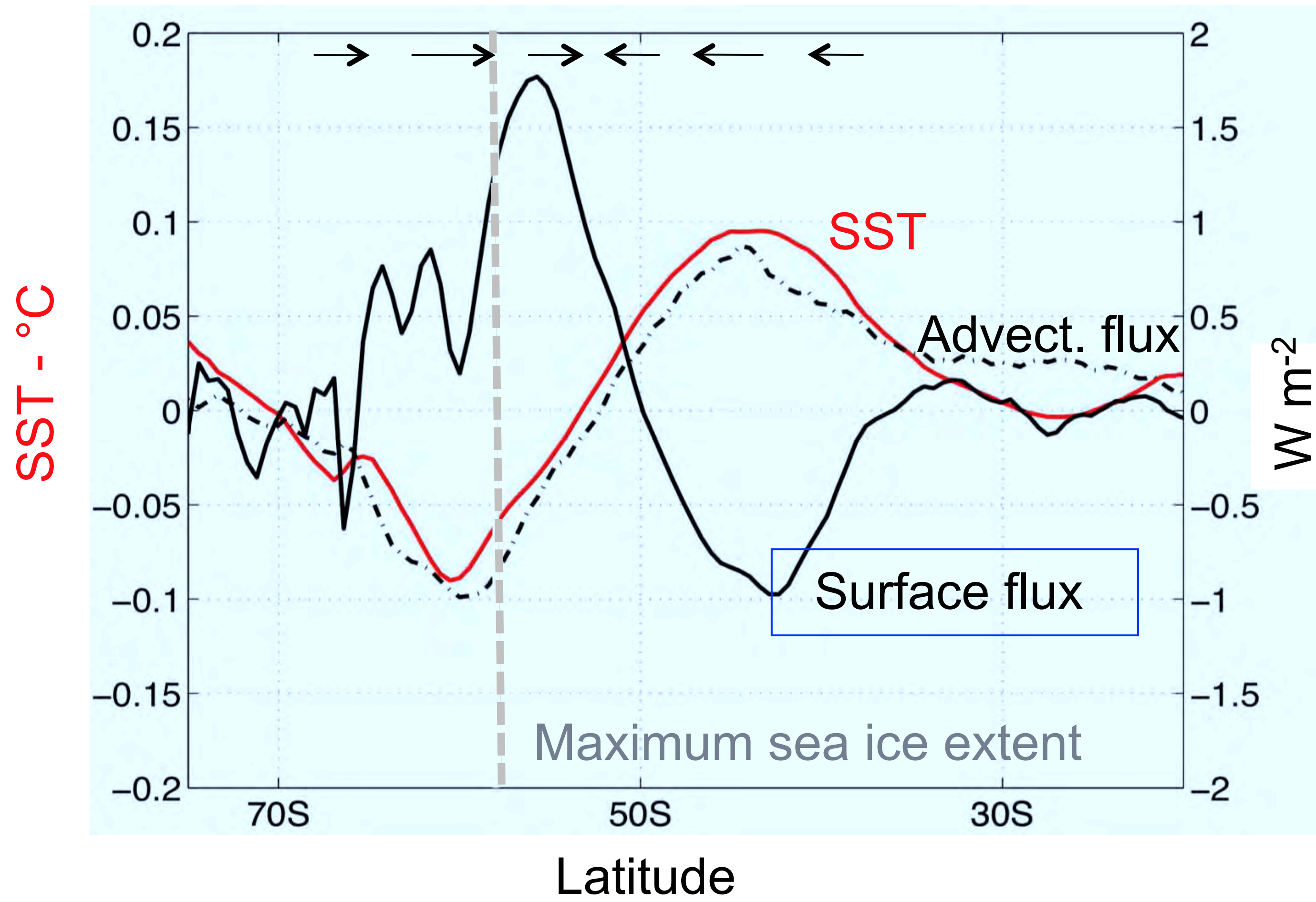
Horizontal advection drives fast SST response & surface flux acts to damp it.

Horizontal advection $\rho\, C_p\, h_s\, v'\, d\overline{T}/dy$

*All quantities are anomalies in year 2-3 except $\overline{T}$

SST and Mixed Layer Heating Terms

Fast response* to abrupt ozone depletion



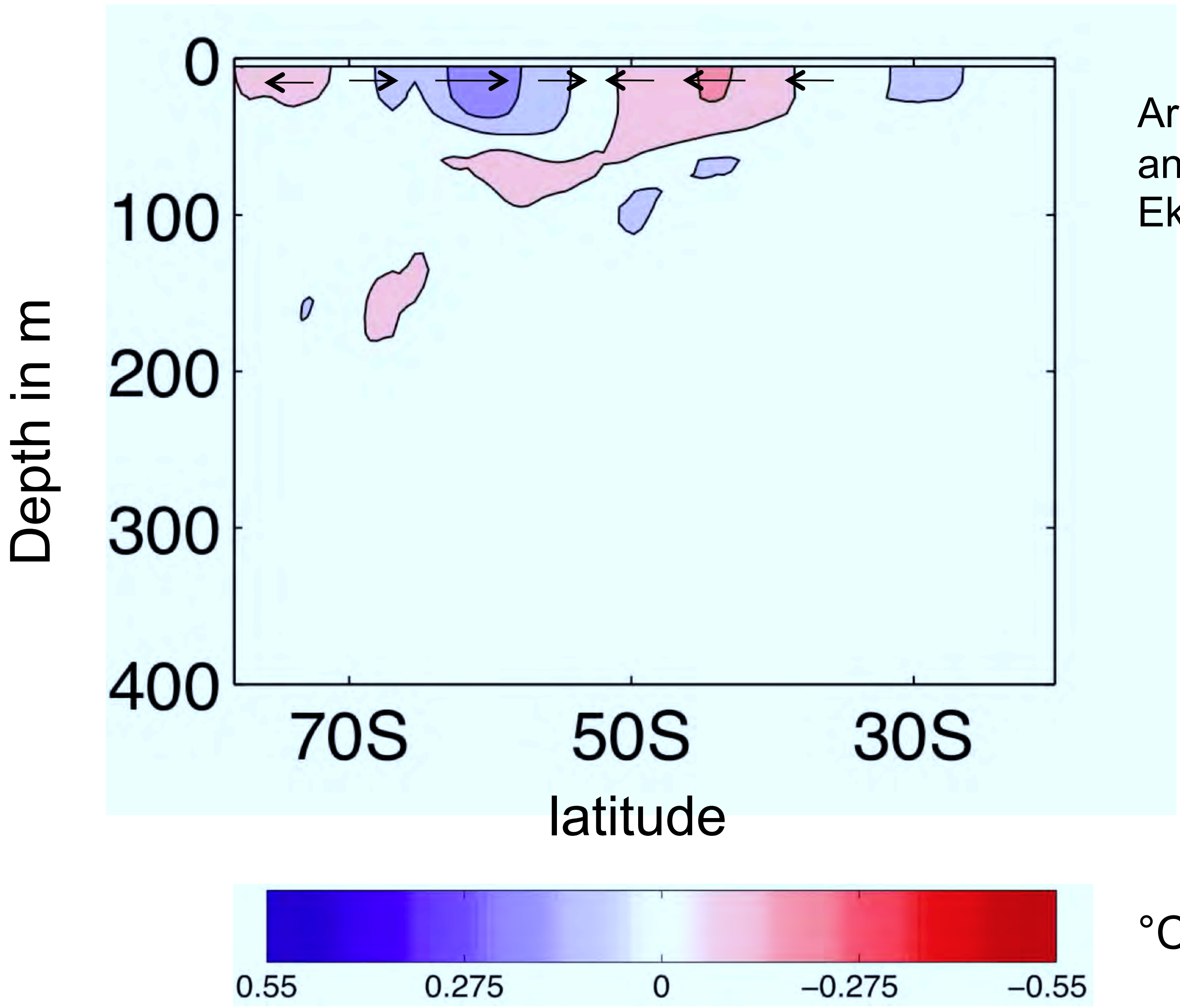
Sea ice and clouds are key to increasing absorbed shortwave

Horizontal advection $\rho\ C_p\ h_s\ v'\ d\overline{T}/dy$

*All quantities are anomalies in year 2-3 except $\overline{T}$

DJF Temperature Response to Abrupt O_3 Depletion

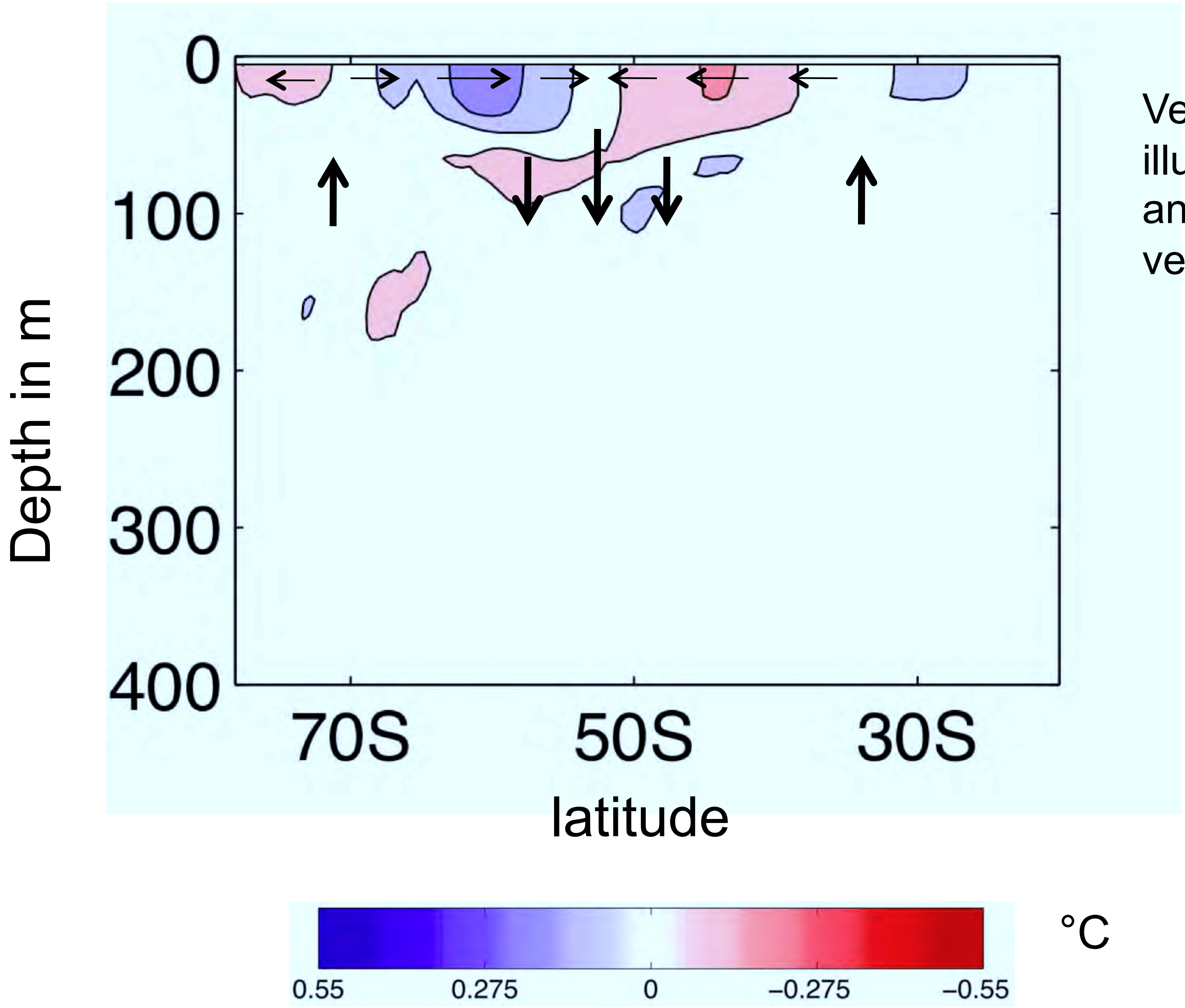
First year (rapid response)



Arrows illustrate anomalous Ekman current

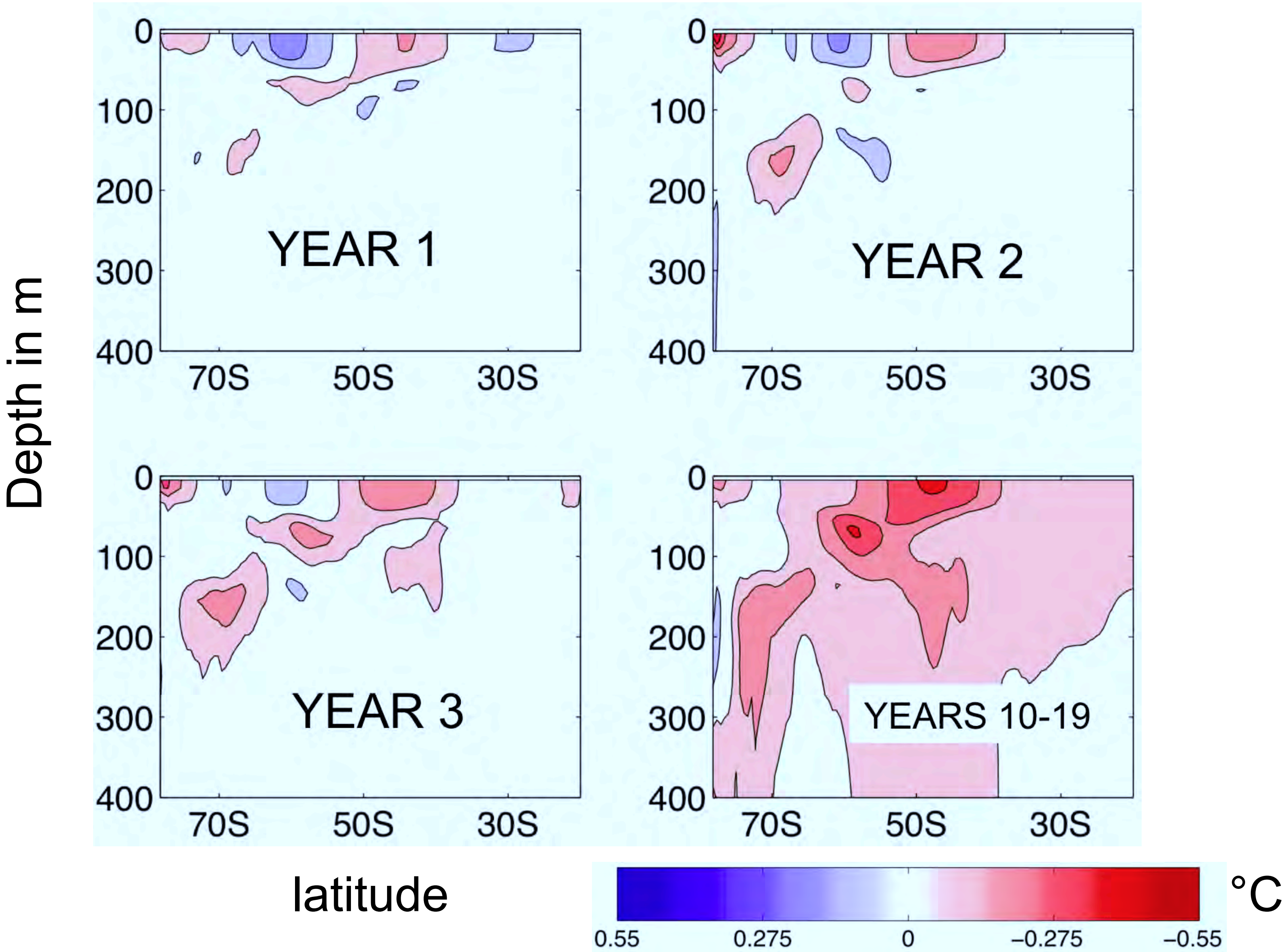
DJF Temperature Response to Abrupt O_3 Depletion

First year (rapid response)

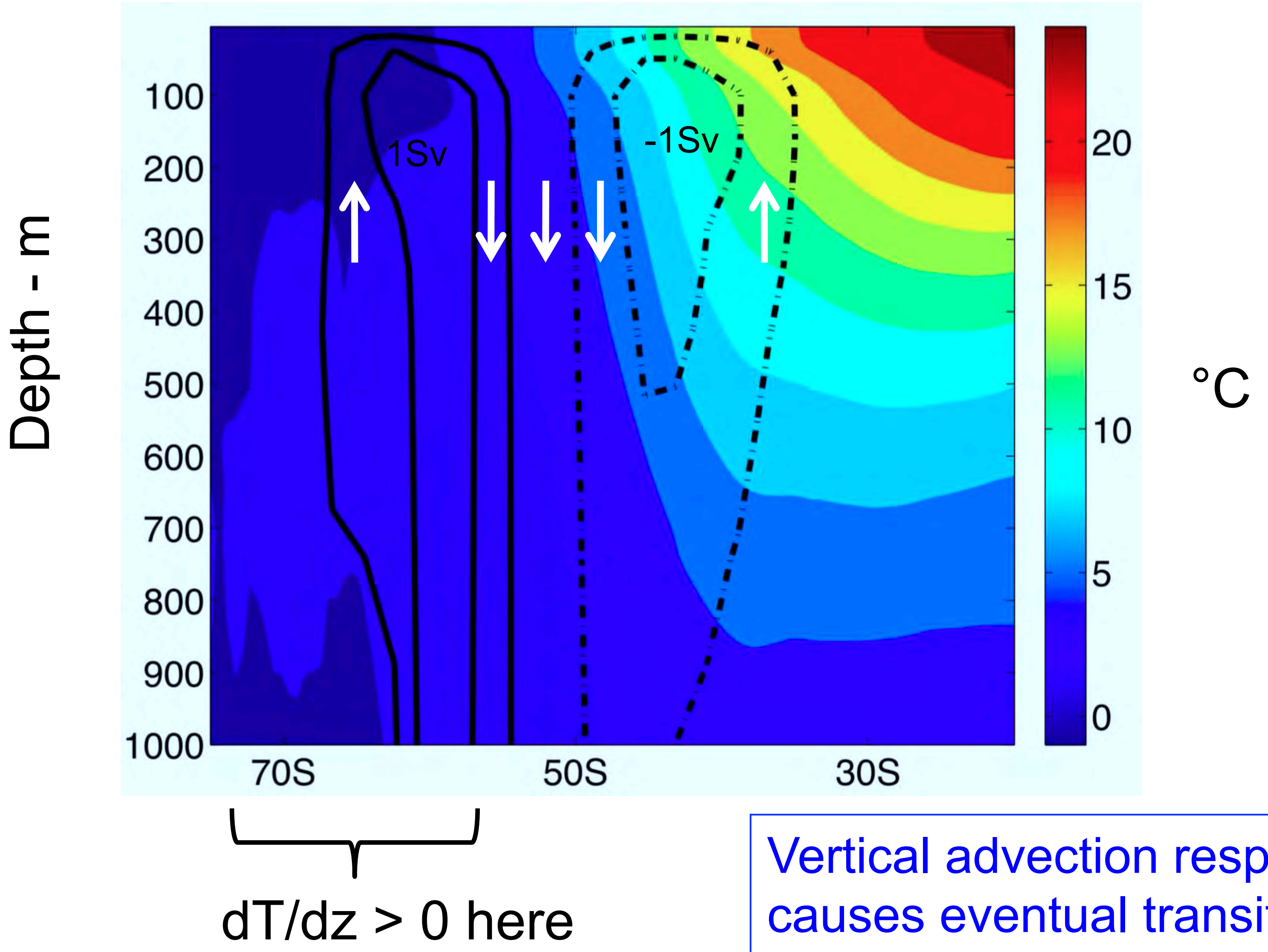


Vertical arrows illustrate anomalous vertical current

DJF Temperature Response to Abrupt O_3 Depletion

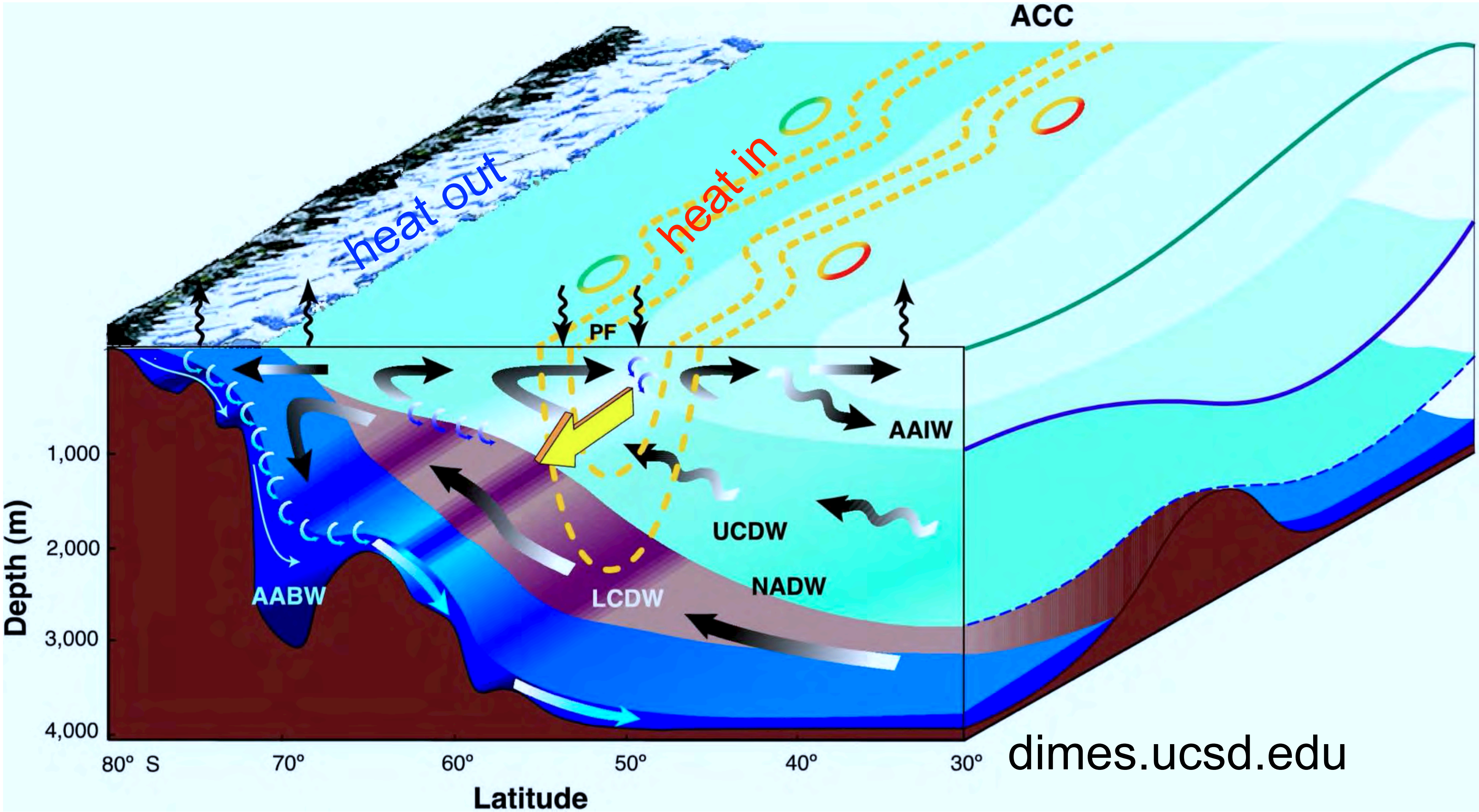


Overturning Streamfunction Response to Abrupt O_3 Depletion
with Unperturbed Temperature for Reference



Vertical advection response causes eventual transitions to higher SST, after ~3 years

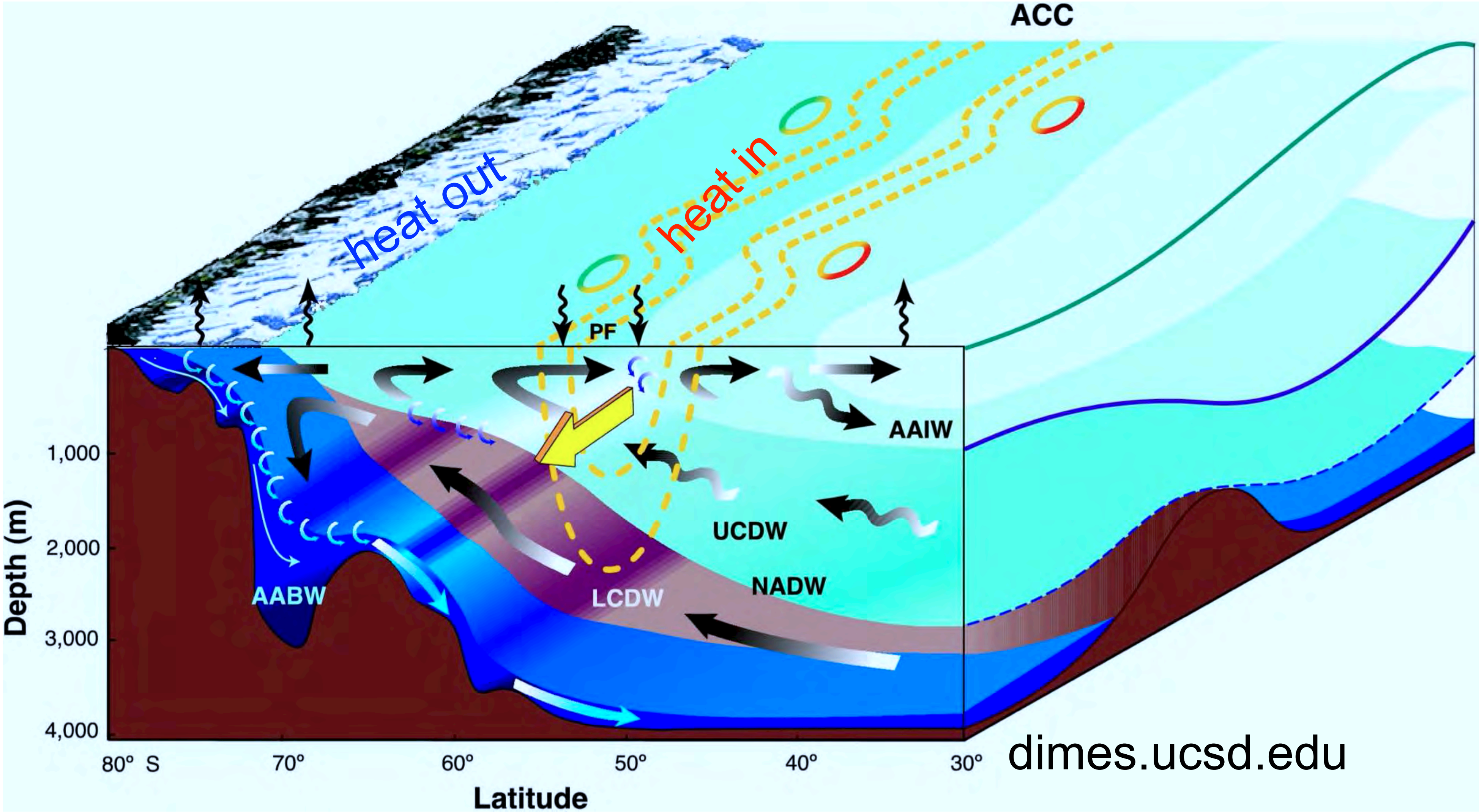
Surface westerly winds on the Southern Ocean cause
•Ekman-driven Eulerian-mean circulation moves heat northward, while eddies move heat southward
•Upwelling of CDW brings heat to the surface in the S. Ocean
Hence heat exits ocean near Antarctica and enters near ACC



dimes.ucsd.edu

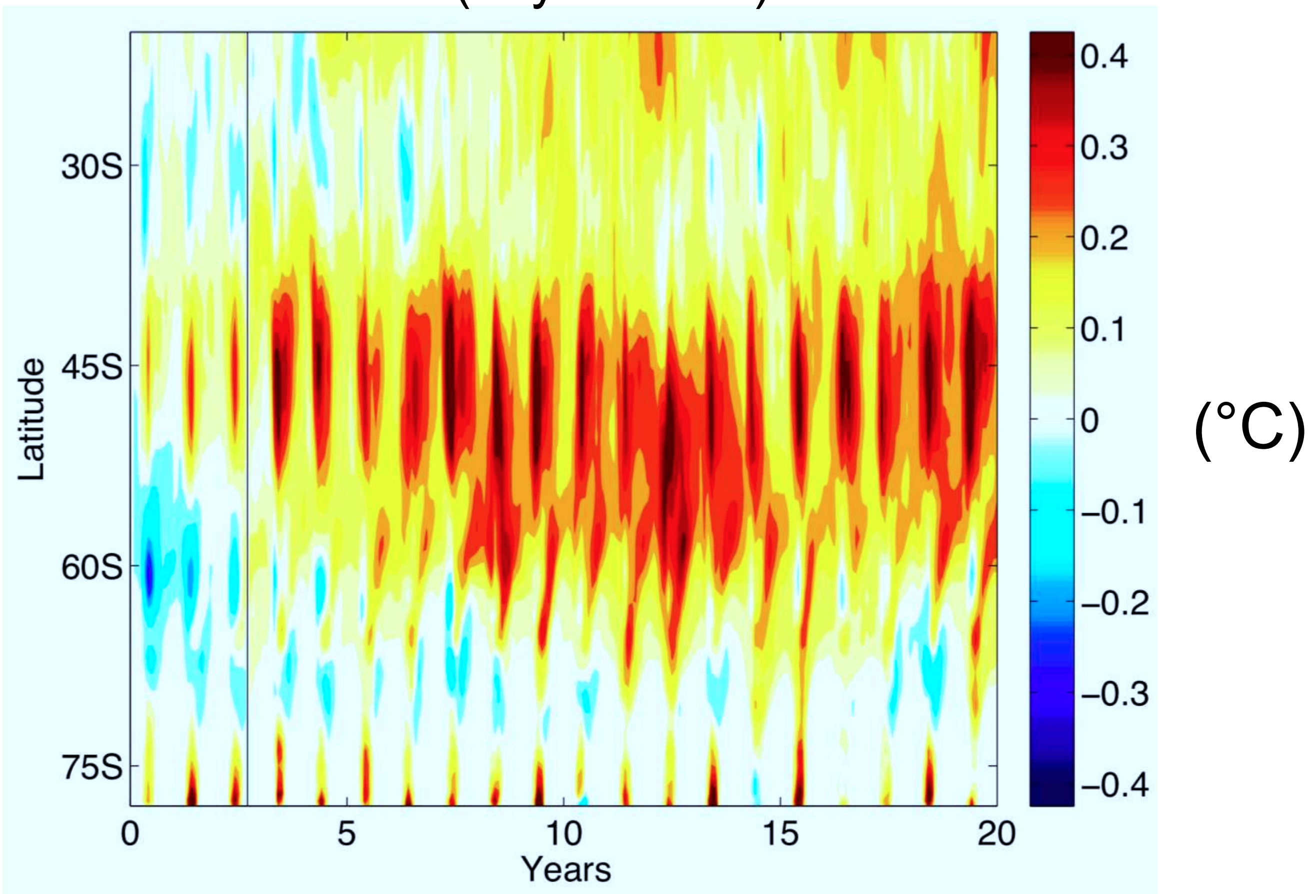
When the surface westerly winds shift southward and blow harder

- Anomalous Ekman circulation cools at ~60S and warms at ~45S
- Upwelling of CDW is enhanced near Antarctica
- Eddy southward heat transport is enhanced (low confidence)
- Enhanced shortwave absorption from sea ice and cloud change



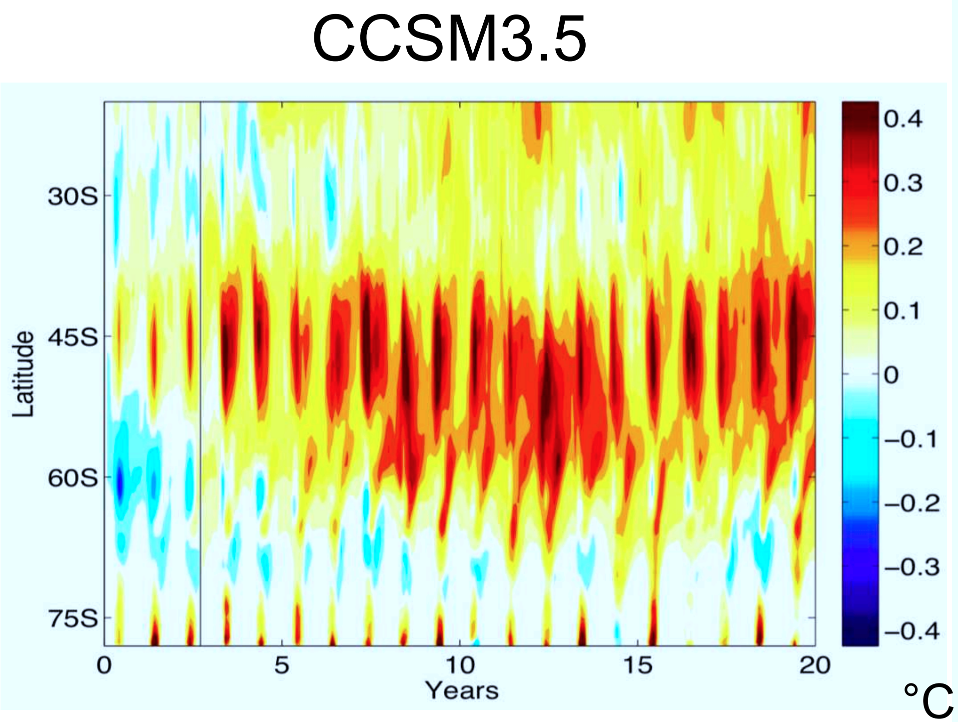
SST Response to Abrupt Ozone Depletion

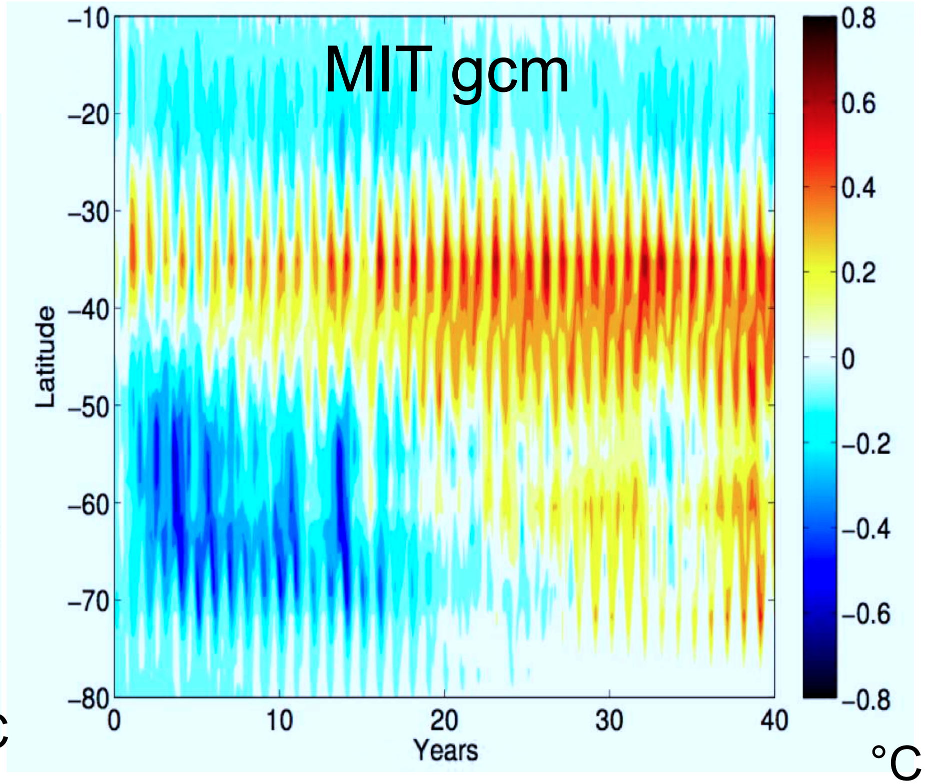
(at year zero)



Fast response is lower SST at 60°S that after ~3 years transitions to higher SST

Zonal Mean SST (°C) Response to Abrupt Ozone Depletion





MIT gcm has much greater cooling response than CCSM3.5 and it lasts several decades. Why? The surface westerlies are too far north and surface feedbacks are much weaker (motionless sea ice).

The rapid response to ozone depletion does cause sea ice to expand… But ozone depletion is not abrupt

Ozone depletion (and increased surface westerly winds) would drive slow response and hence is not the cause of sea ice expansion, according to CCSM3.5