Why is Antarctic Sea Ice Expanding

by Cecilia Bitz

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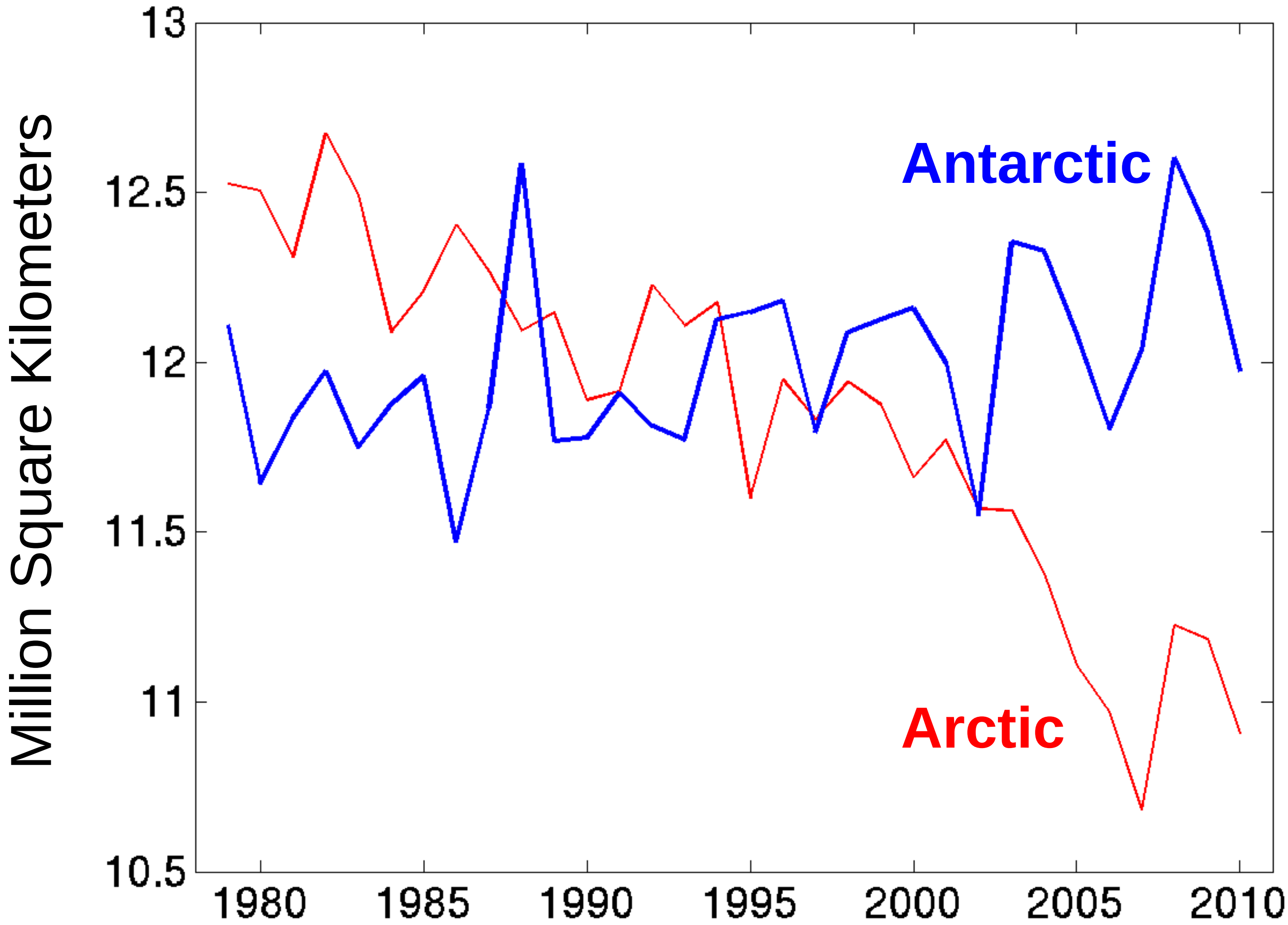
with thanks to UW sea ice enthusiasts (Clark, Ed, Emily, Hansi, Torge, Kelly, Brian, Zach) and many others including Lorenzo Polvani, John Marshall, David Ferriera, Jean-François Lamarque, Peter Gent, Frank Bryan, and the Peta-Apps team

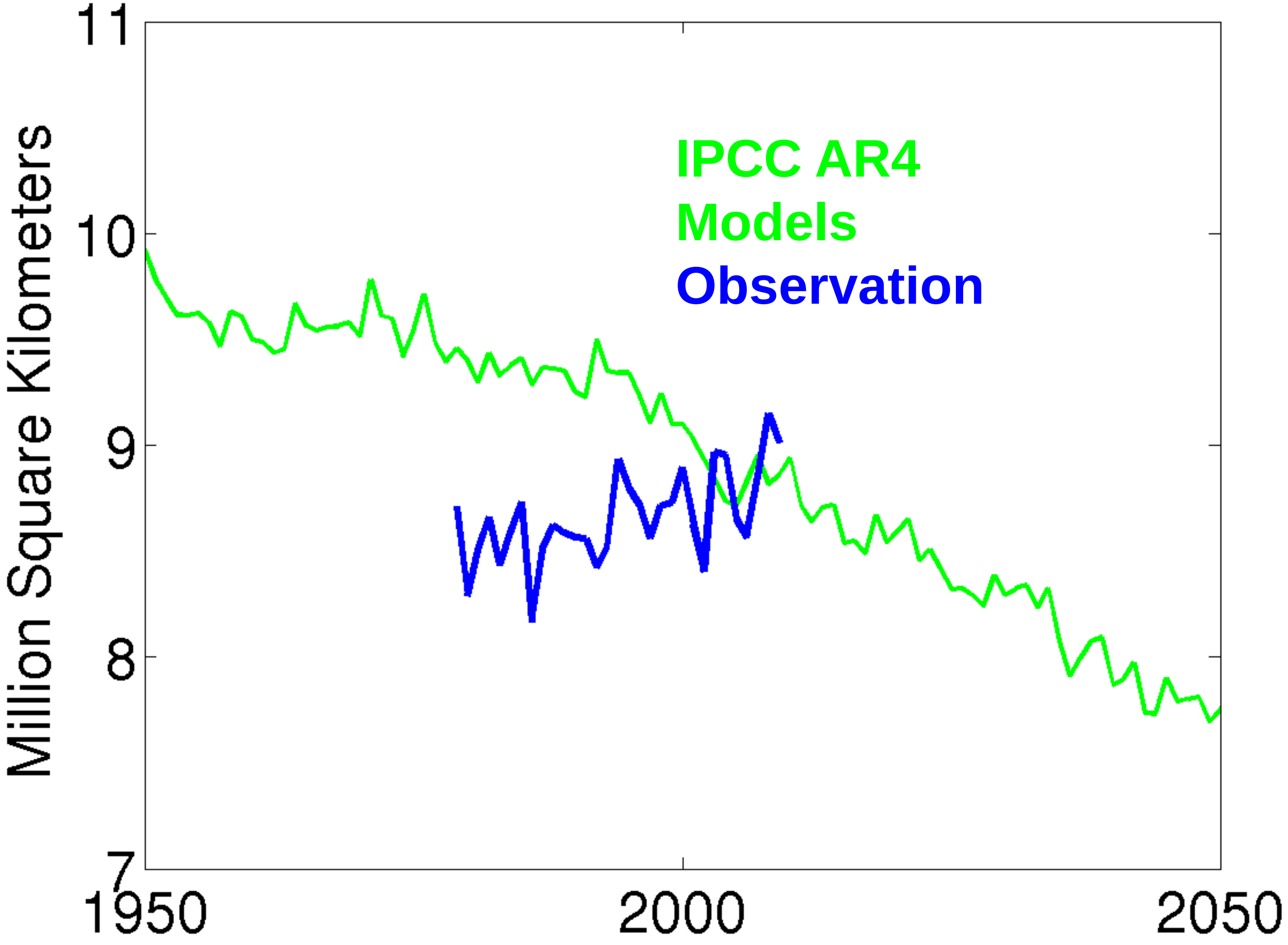
University of Washington
Atmospheric Sciences

NSF

Annual Mean Sea ice extent 1979-2010



Antarctic Annual Sea Ice Area 1979-2010
AR4 Models A1B scenario



Antarctic February Sea Ice Area 1979-2010
AR5 Models RCP4.5

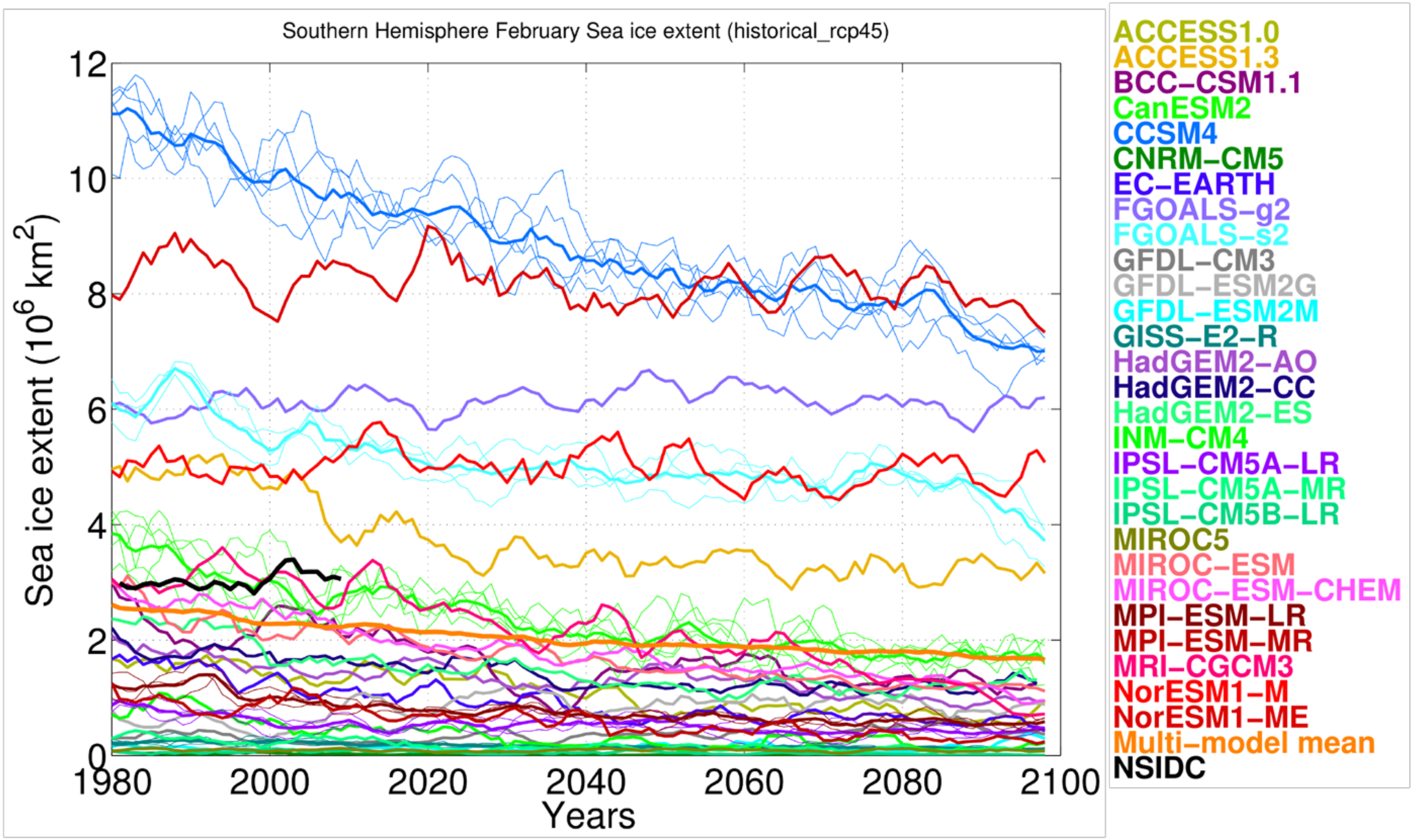


Figure by F Massonet

Antarctic February Sea Ice Area 1979-2010
AR5 Models

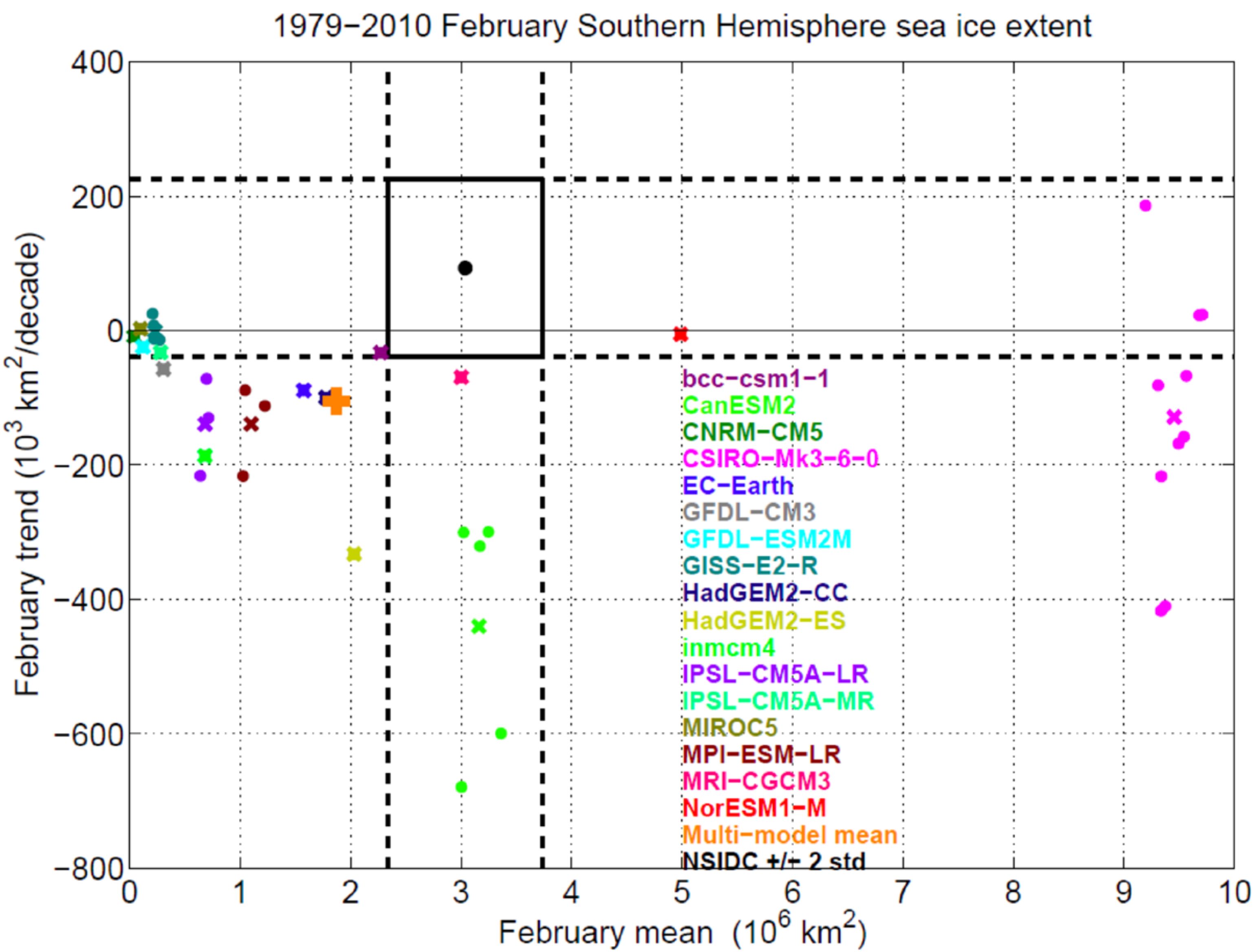
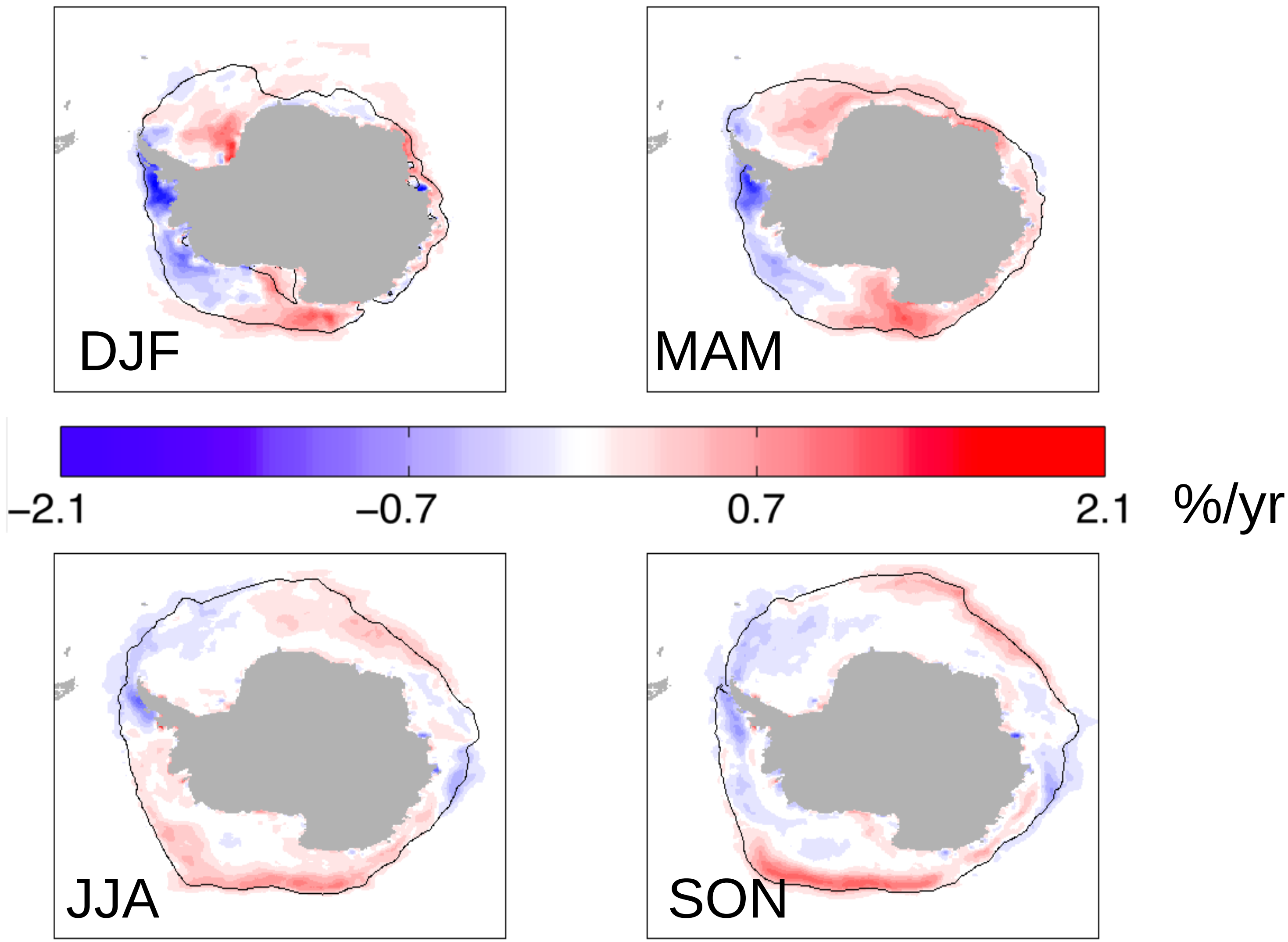


Figure by F Massonet

Concentration Linear Trends 1979-2011



NASA team algorithm

Antarctic sea ice trends by month

Largest, but insignificant in Autumn

Wimpy in DJF …

Only annual mean trend is significant

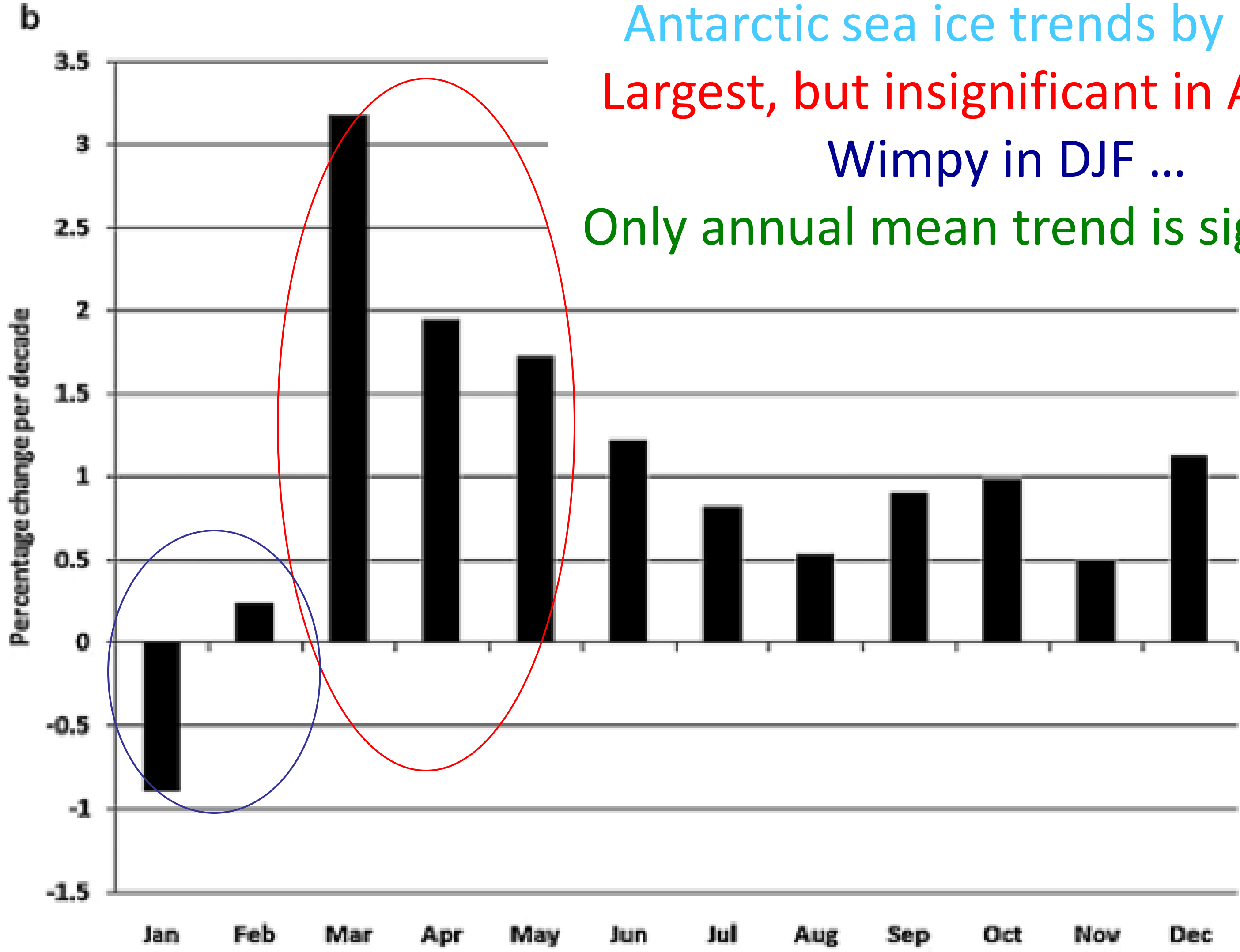
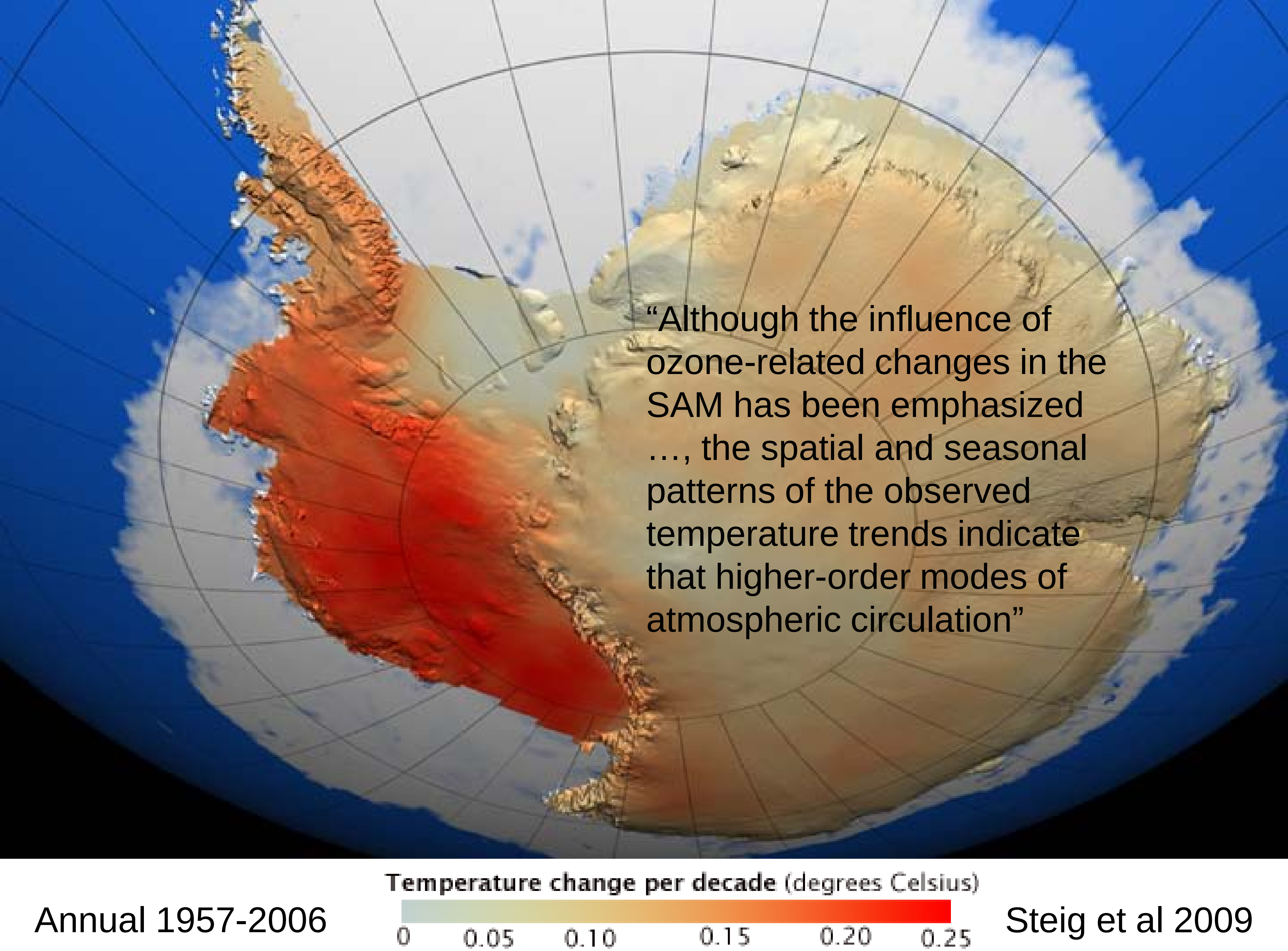


Figure 1. Monthly trends in sea ice extent for 1979–2007

Turner et al 2009

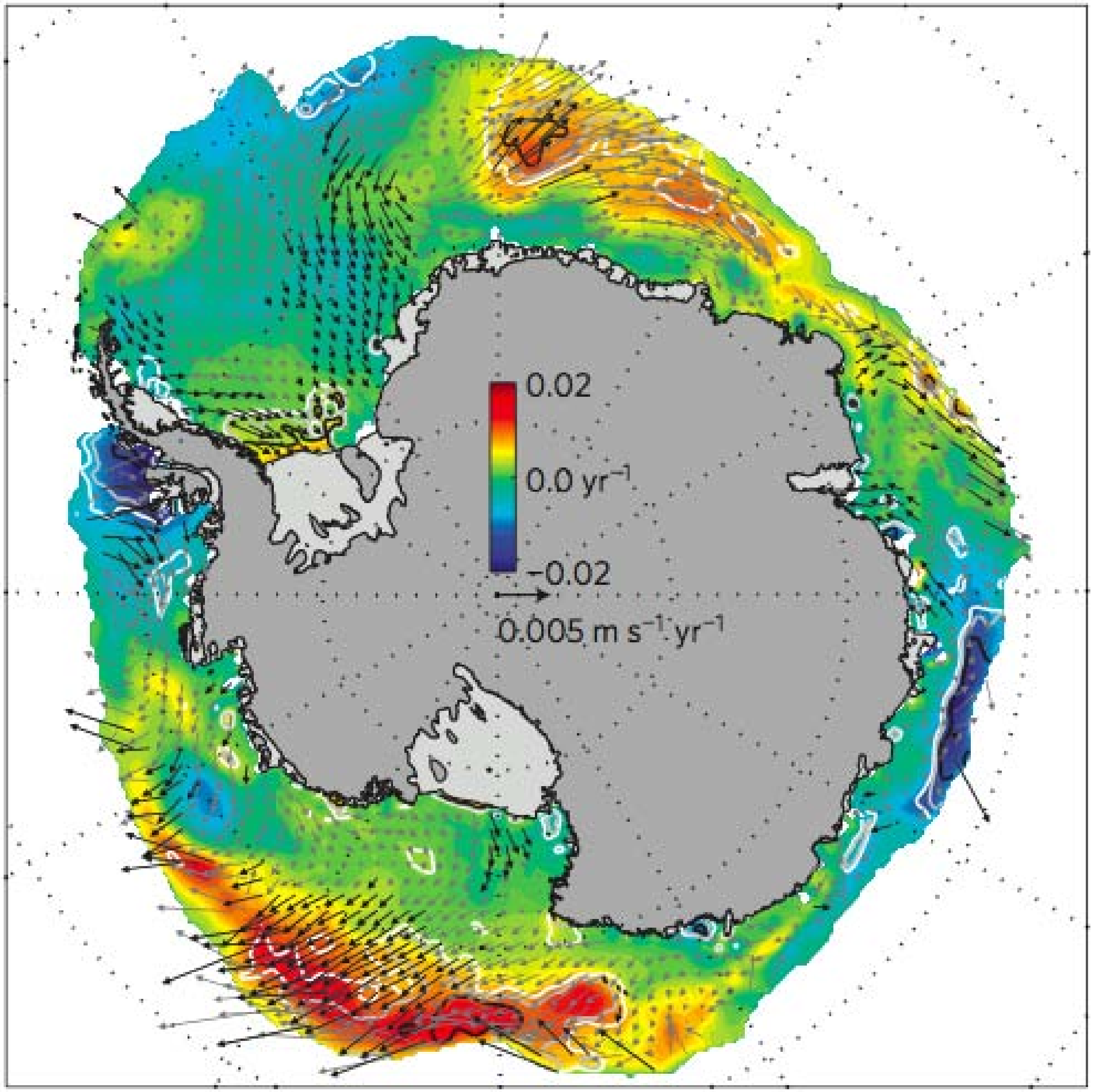


“Although the influence of ozone-related changes in the SAM has been emphasized …, the spatial and seasonal patterns of the observed temperature trends indicate that higher-order modes of atmospheric circulation”

Annual 1957-2006

Steig et al 2009

1992-2010 Apr-Oct* Trends in Ice Fraction and Ice Motion



Holland and Kwok, 2012

*due to observational limitations

Antarctic Sea Ice Trend Drivers

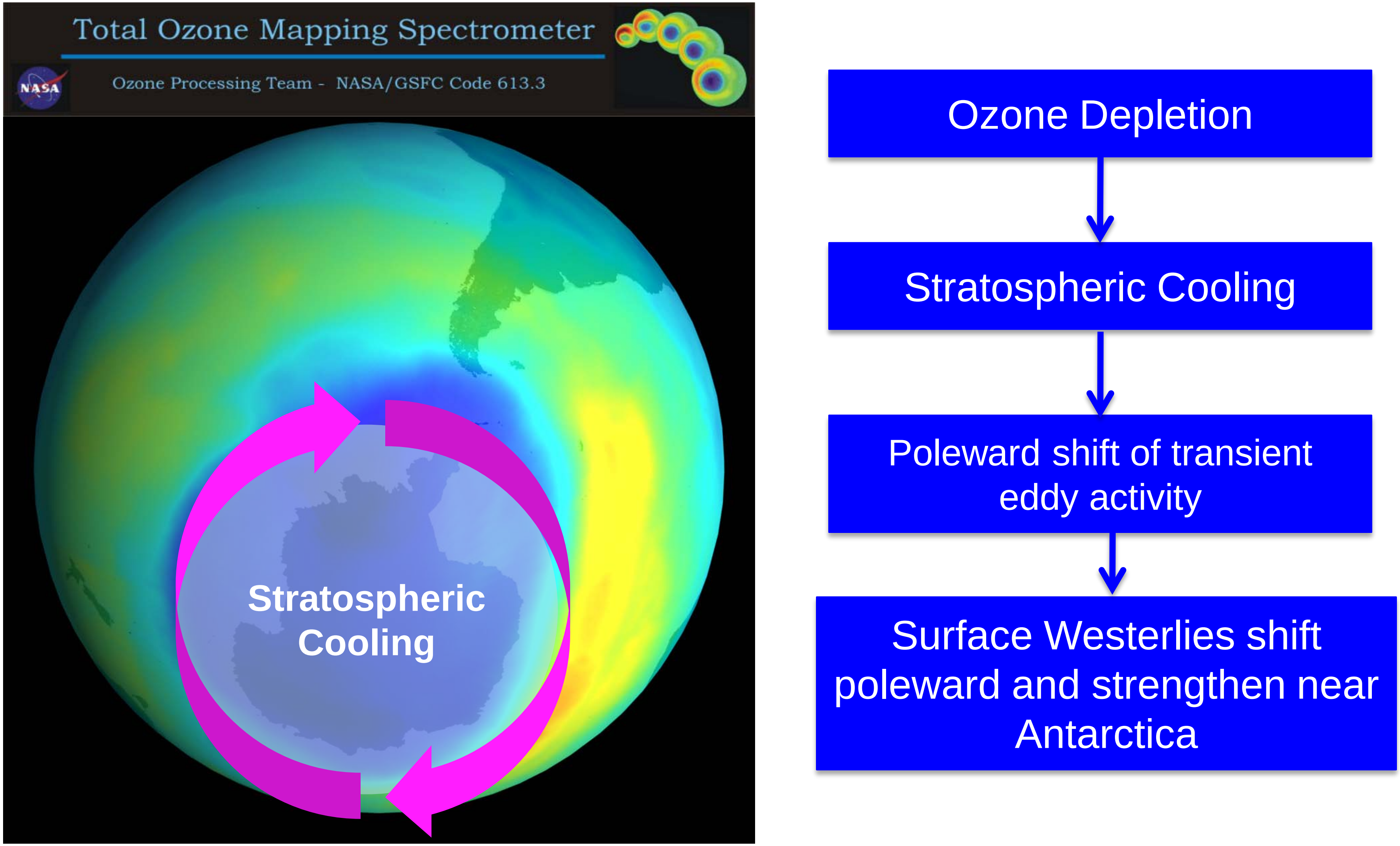
Loss in the Bellingshausen Sea appears to be via tropical teleconnections and/or azonal wind trends (e.g., Ding et al, 2011)

Expansion in Ross Sea in cold season appears to be due in part to meridional winds (Holland and Kwok, 2012) though SST must cool to permit expansion (not shown how)

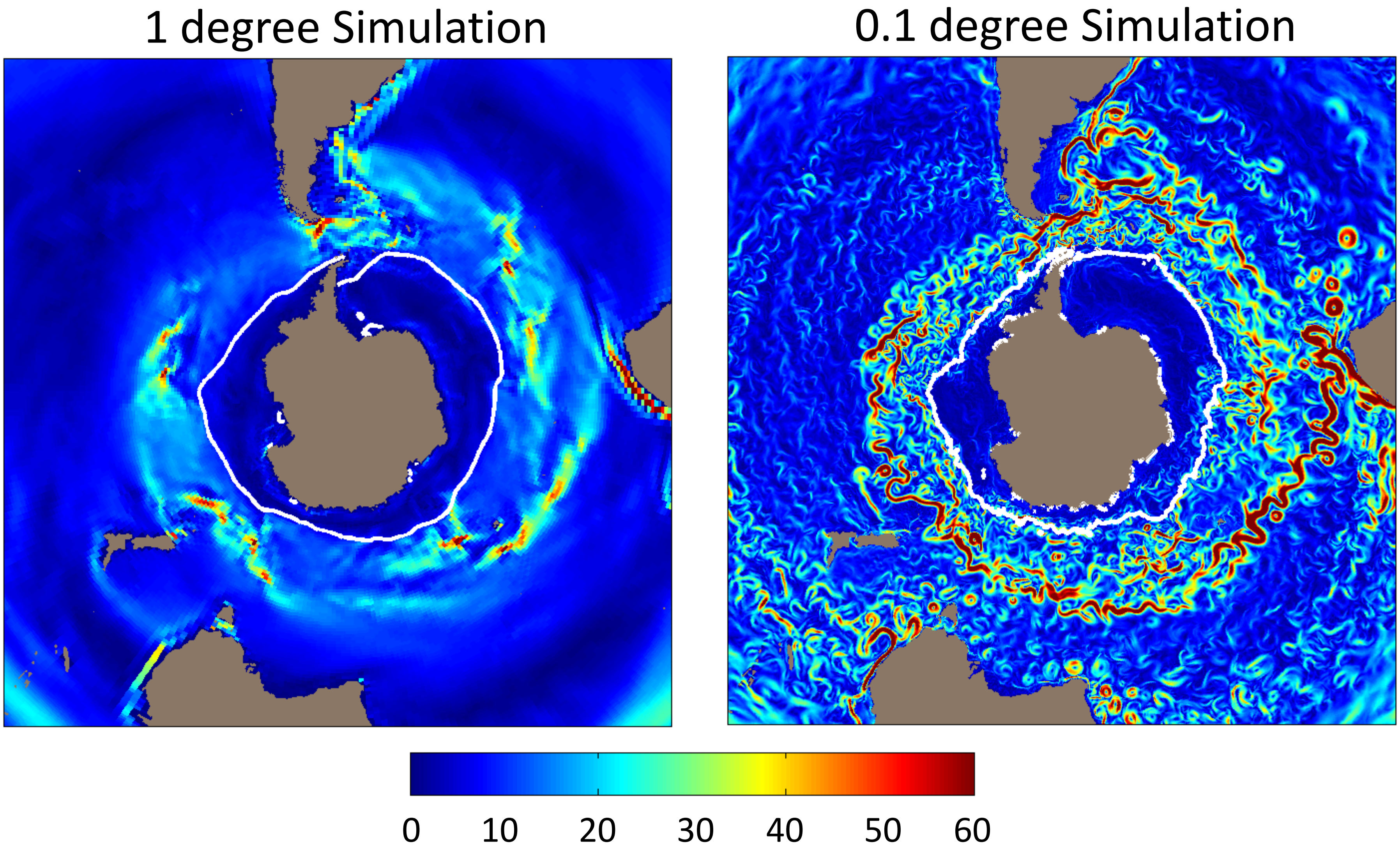
But there are multiple theories for the expansion elsewhere and in other seasons

1)SAM trends (driven by ozone primarily, Turner et al 2009)

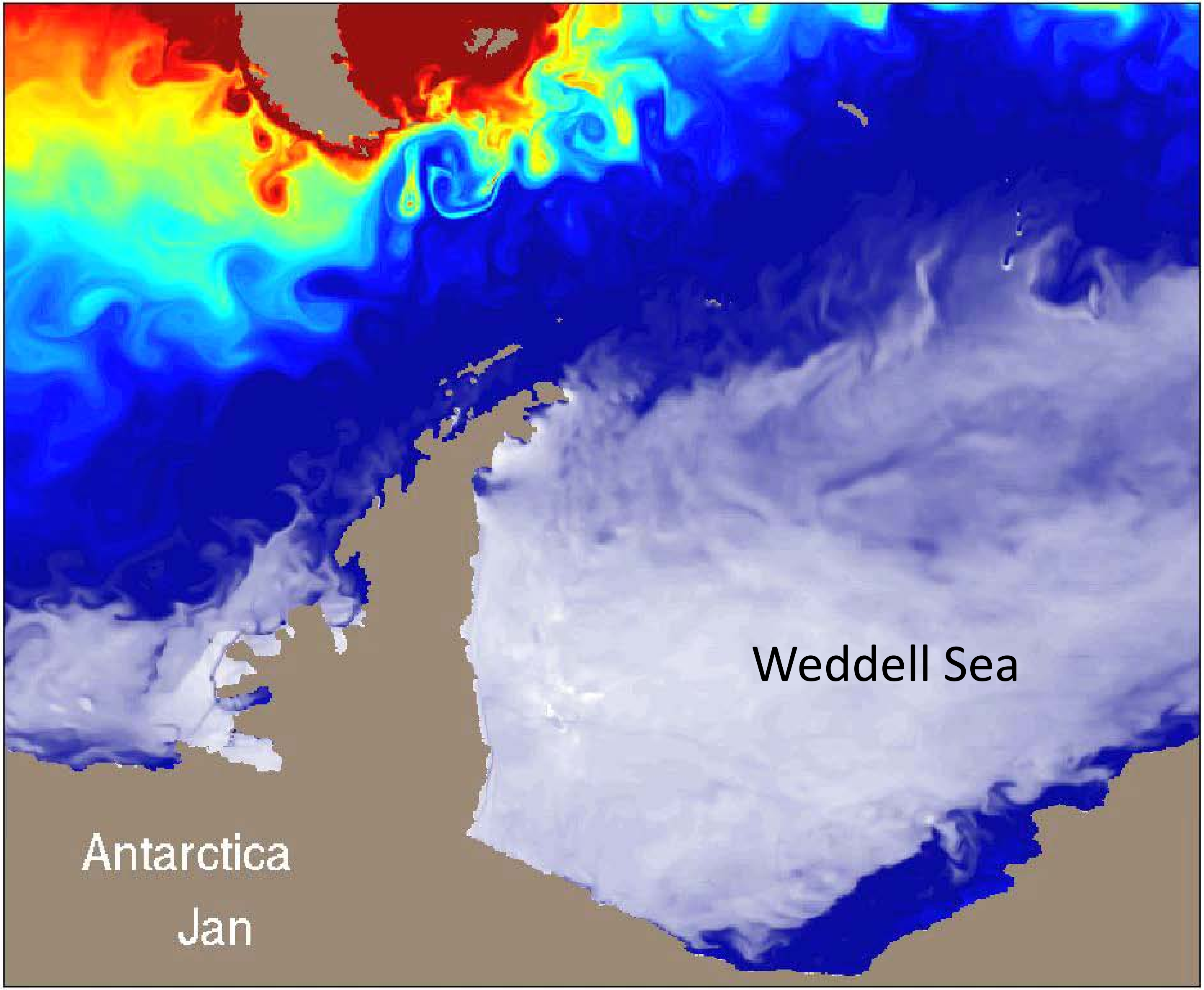
2)Freshwater trends (Bitz et al 2006; Zhang, 2007; Aicken and England 2008; Liu and Curry, 2011)


Total Ozone Mapping Spectrometer
NASA
Ozone Processing Team - NASA/GSFC Code 613.3
Stratospheric Cooling
Ozone Depletion
Stratospheric Cooling
Poleward shift of transient eddy activity
Surface Westerlies shift poleward and strengthen near Antarctica

Simulated Surface Currents and Sea Ice Extent Around Antarctica

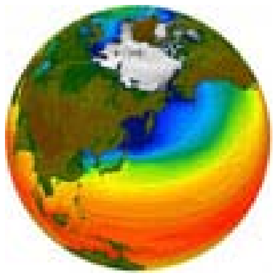


Current Speed in cm/s for randomly chosen October



Animation at www.atmos.uw.edu:~/bitz/bothmovies/icesst.mov

Simulations using Community Climate System Model Version 3.5 with Ozone Anomaly from SPARC datasets for CMIP5 (Bitz and Polvani, 2012)



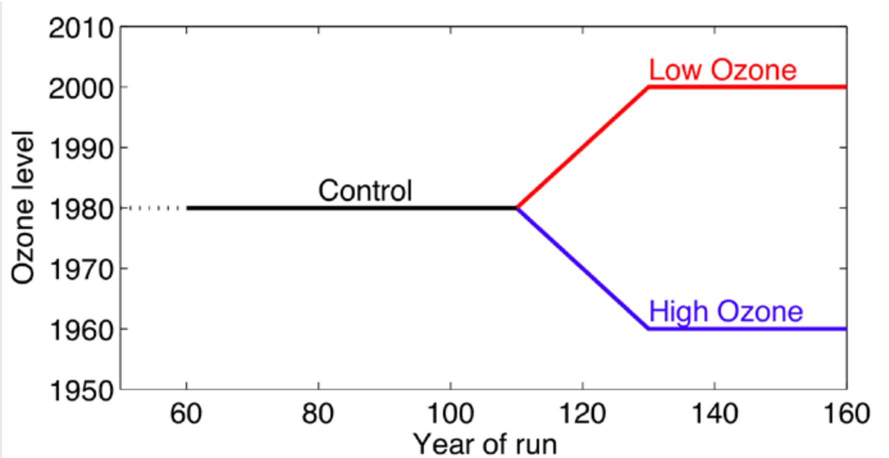
At two ozone levels:

- High Ozone (1940s) or "Normal"
- Low Ozone (1997) or "Most depleted"

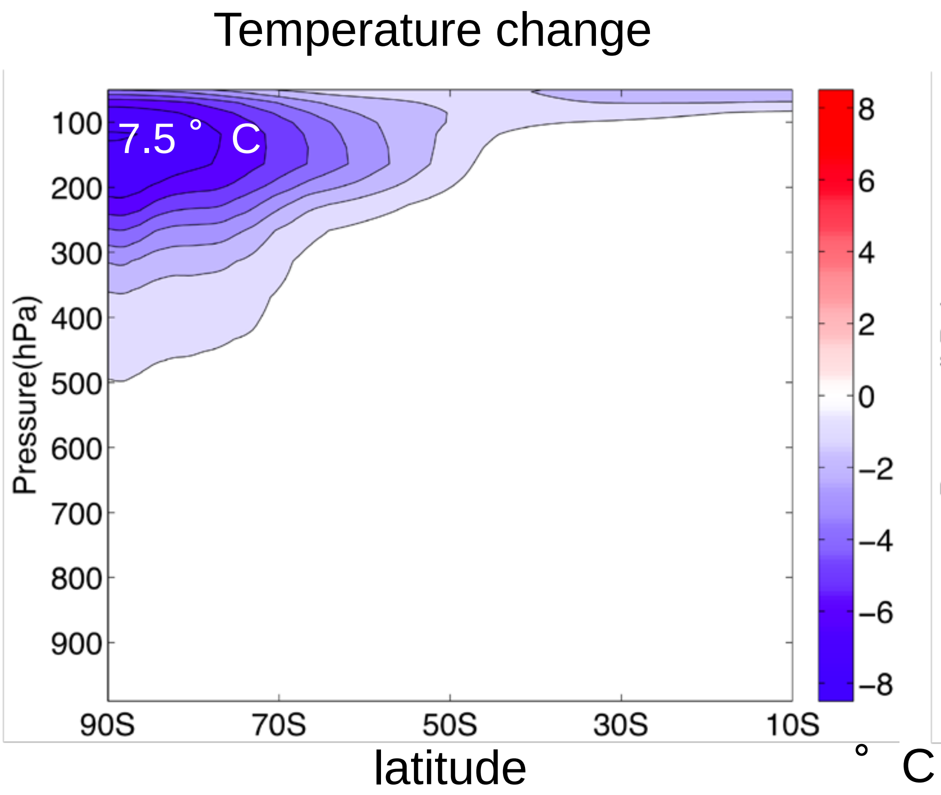
At two resolutions:

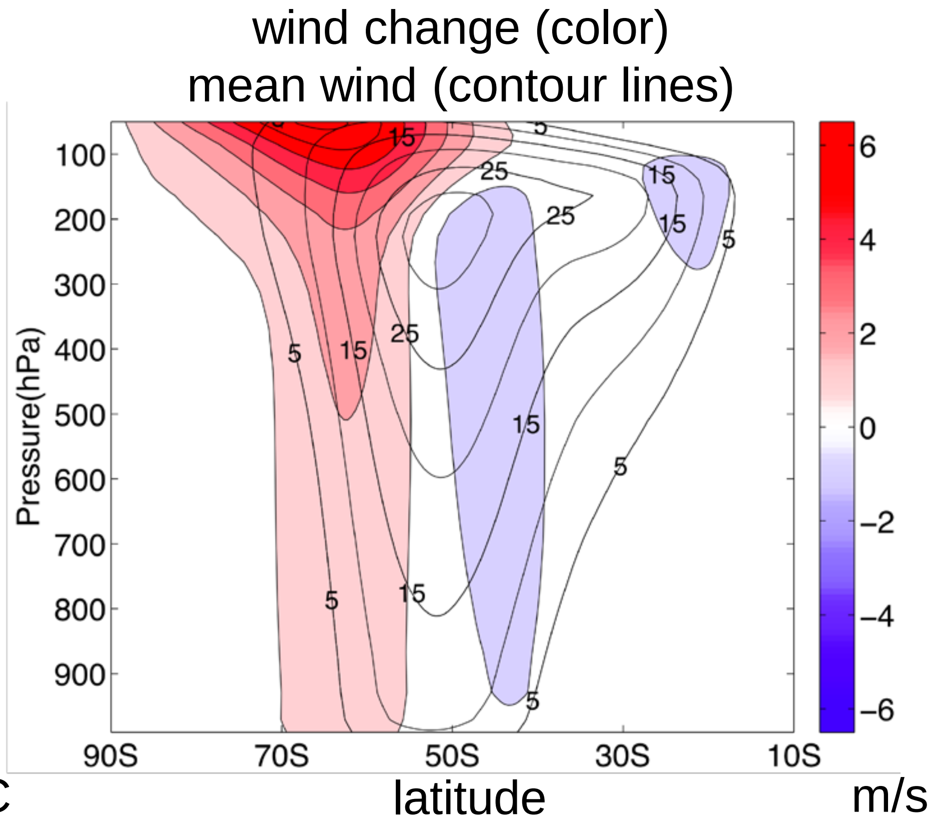
- Coarse - 1 degree ocean and sea ice
- Fine – 0.10 degree ocean and sea ice

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.



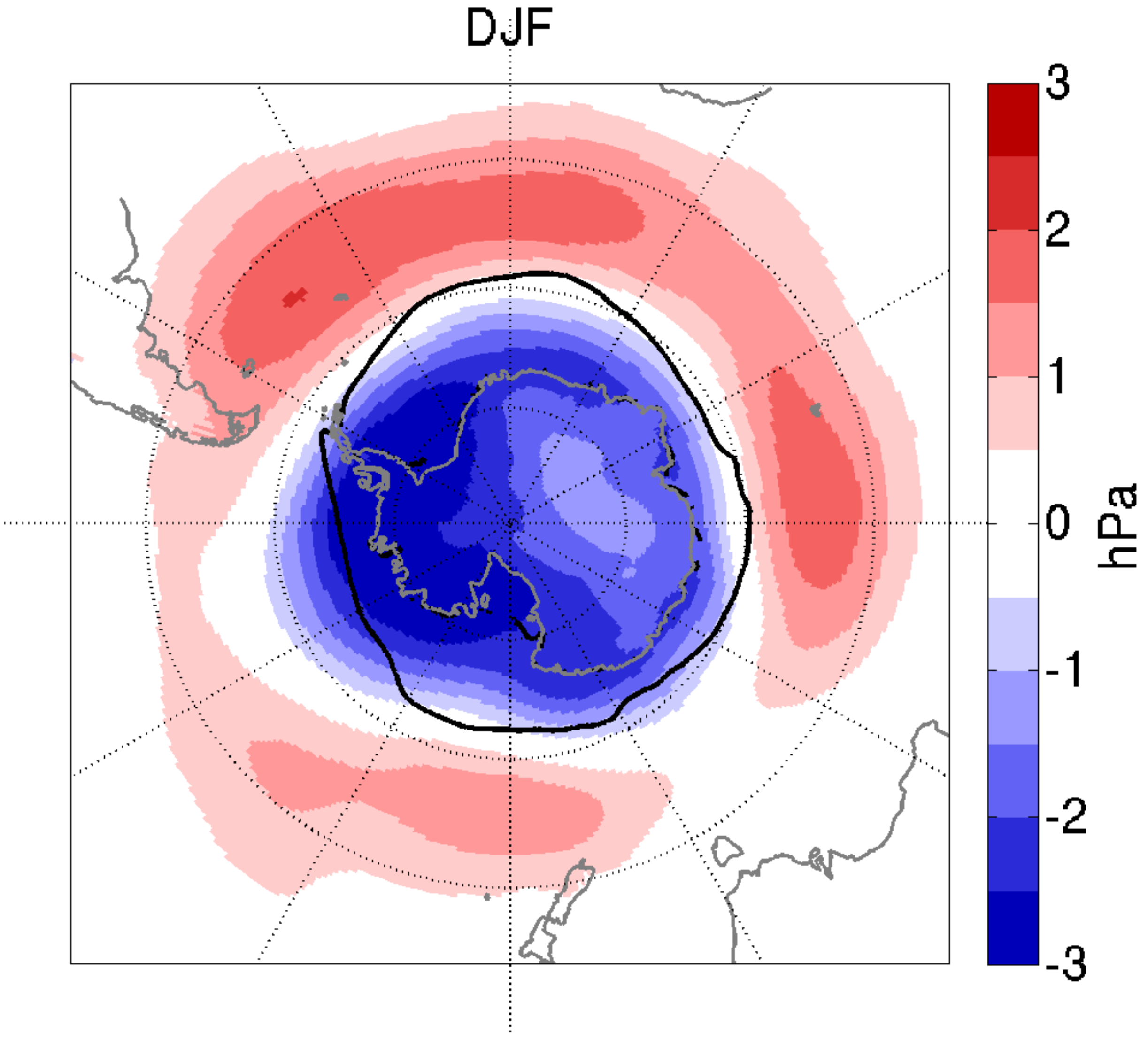
DJF Atmospheric Zonal-Mean Response to Depleting Ozone





Low Resolution Model Sensitivity of Temperature and Winds
is about 15-20% greater

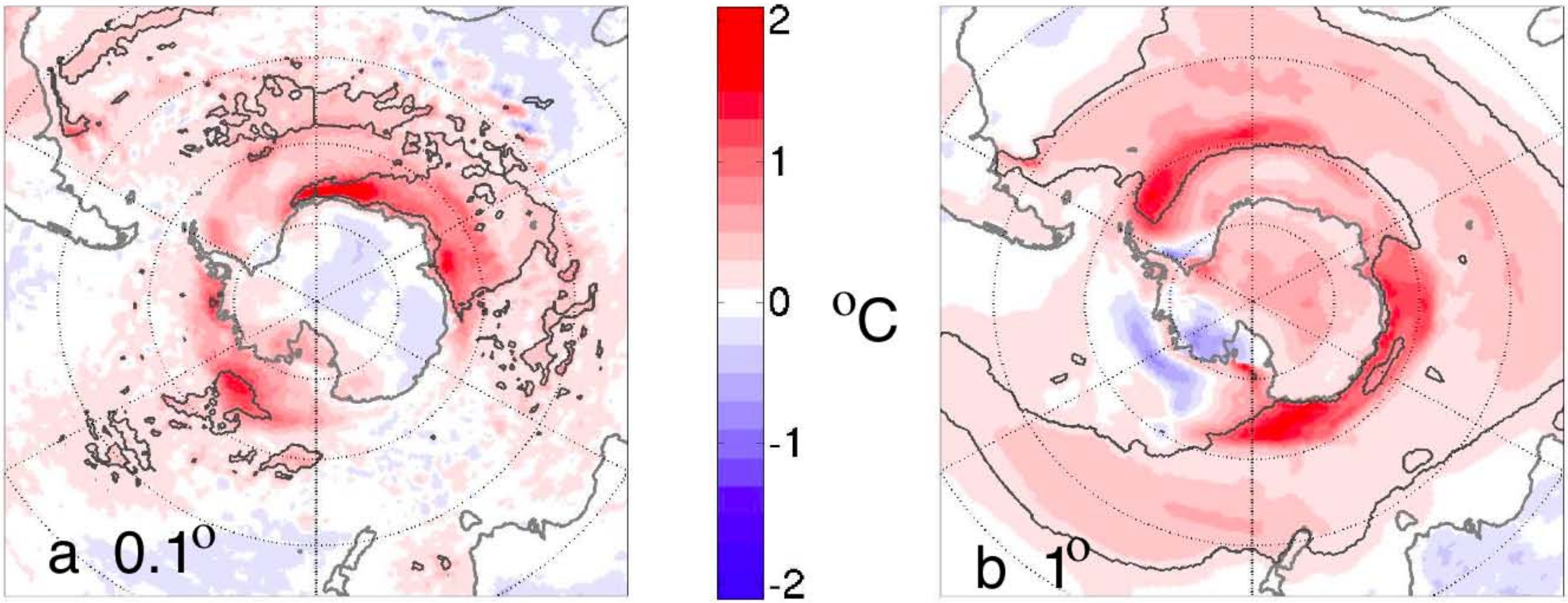
DJF Sea Level Pressure Response to Depleting Ozone



Annual Mean Surface Air Temperature Response to Ozone Loss

0.1° Simulations

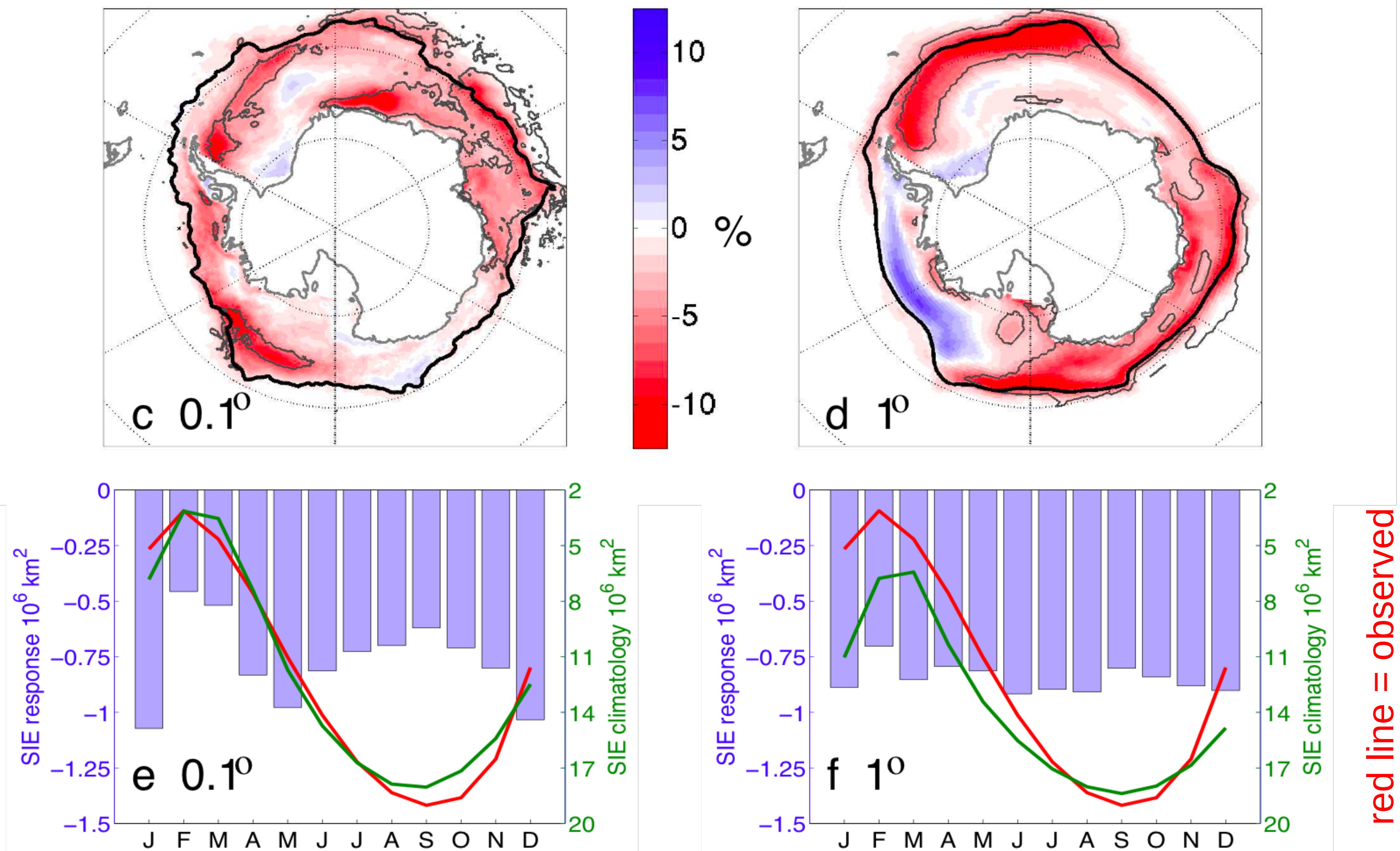
1° Simulations



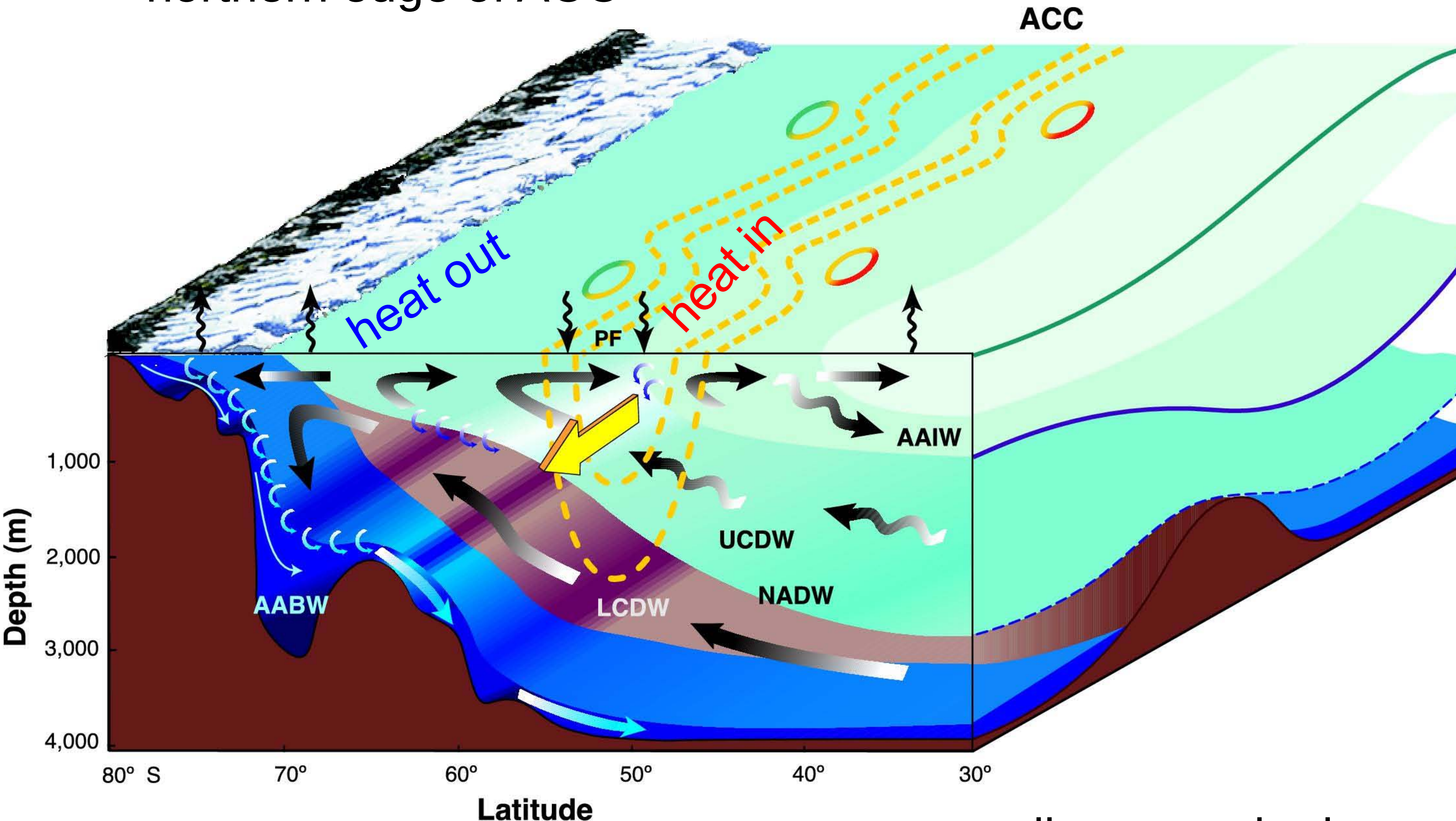
Bitz and Polvani, 2012

Annual Mean Sea Ice Concentration Response to Ozone Loss

0.1° Simulations | 1° Simulations



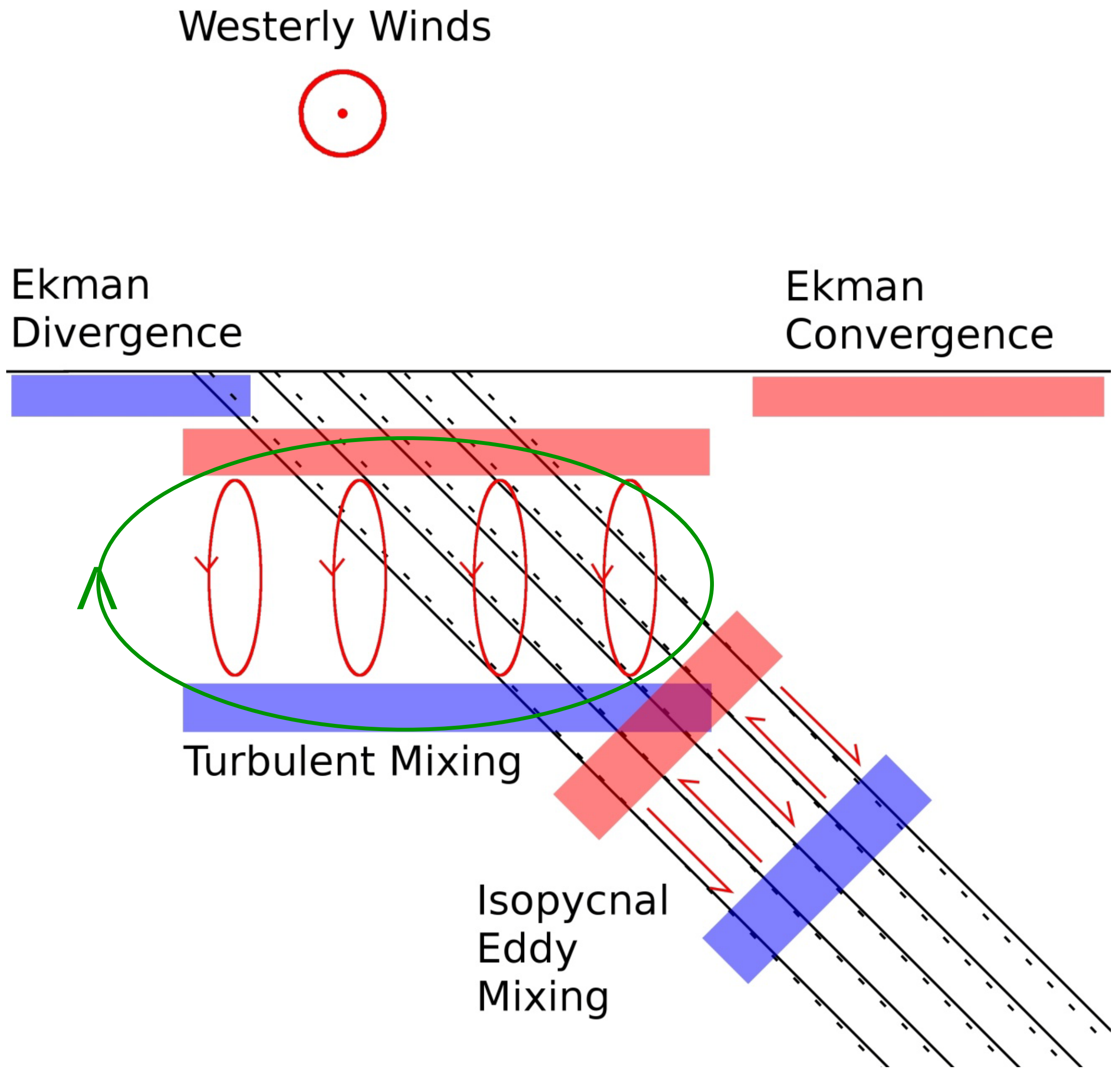
Surface westerly winds blow on the Southern Ocean
Heat exits ocean near Antarctica and enters on northern edge of ACC



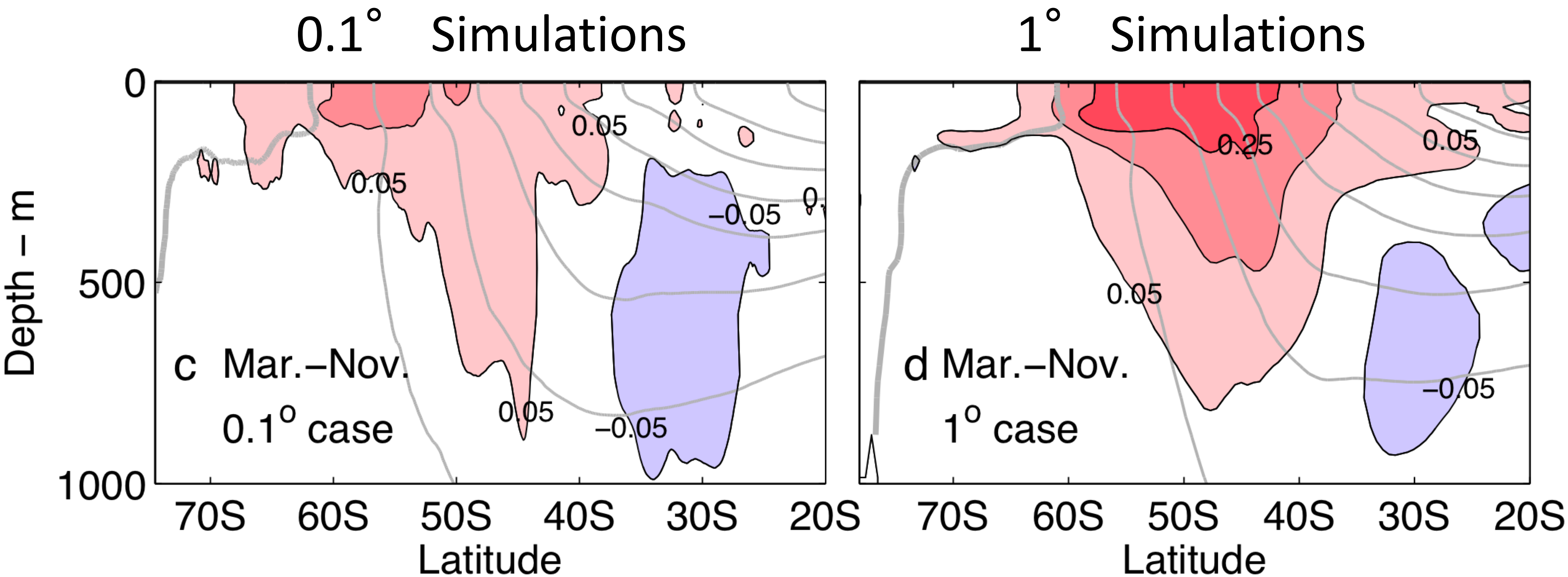
dimes.ucsd.edu

ACC and mode water summary

Clark Kirkman 2011



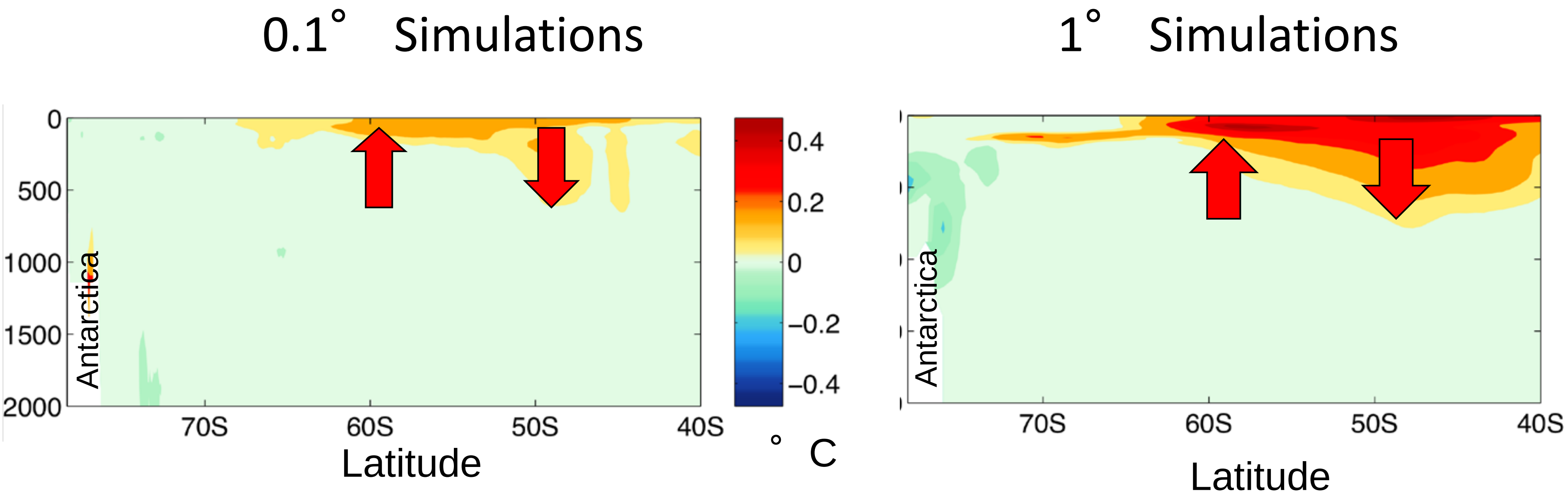
Ocean Temperature Response to Ozone Depletion for Mar. to Nov. (about the same annually)



Color contour interval is 0.1 deg Celsius

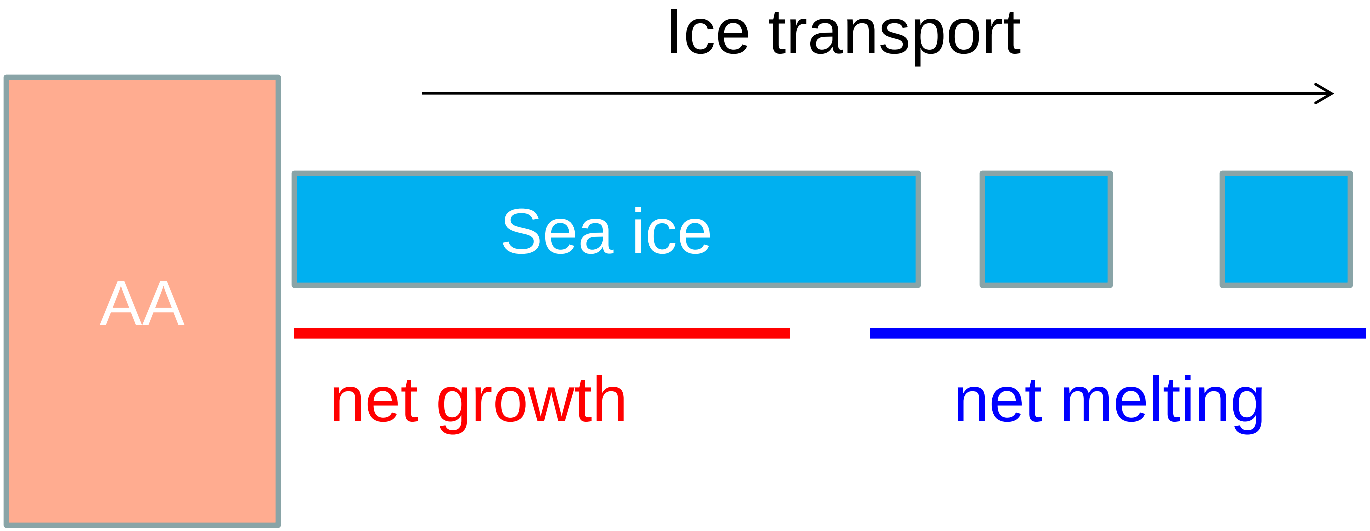
Fine resolution ocean has a weaker response

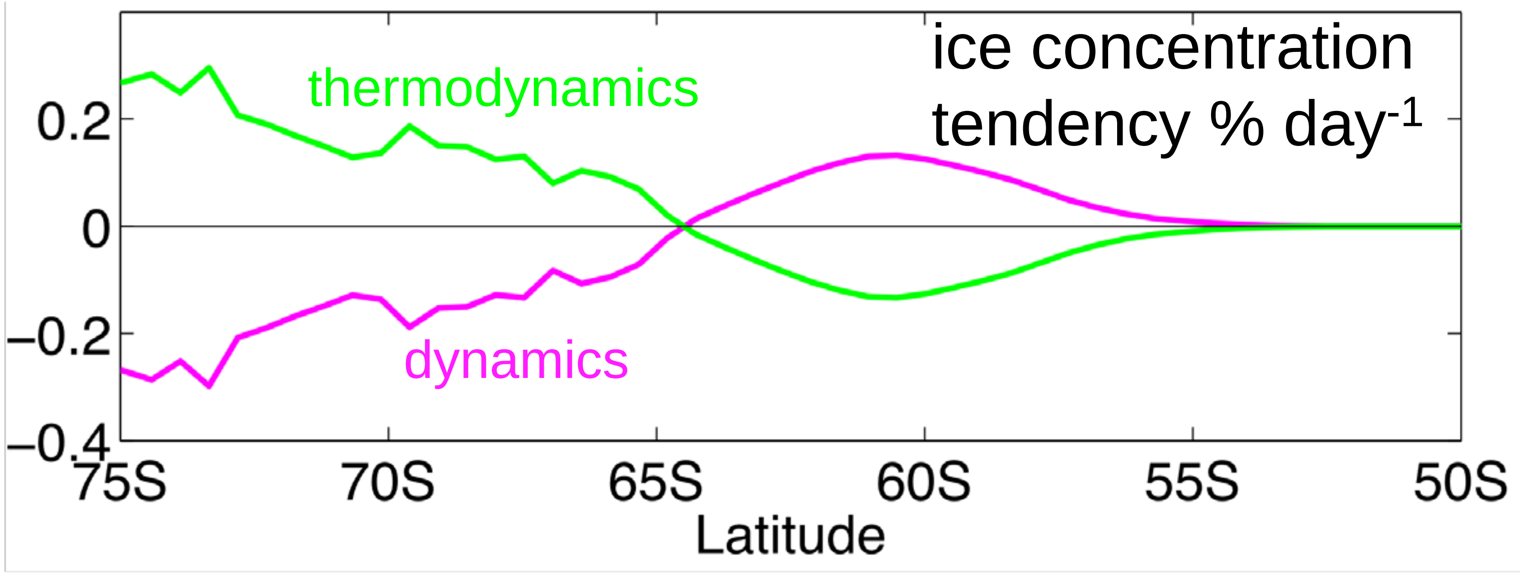
Annual Zonal Mean Ocean Temperature Response to Ozone Loss



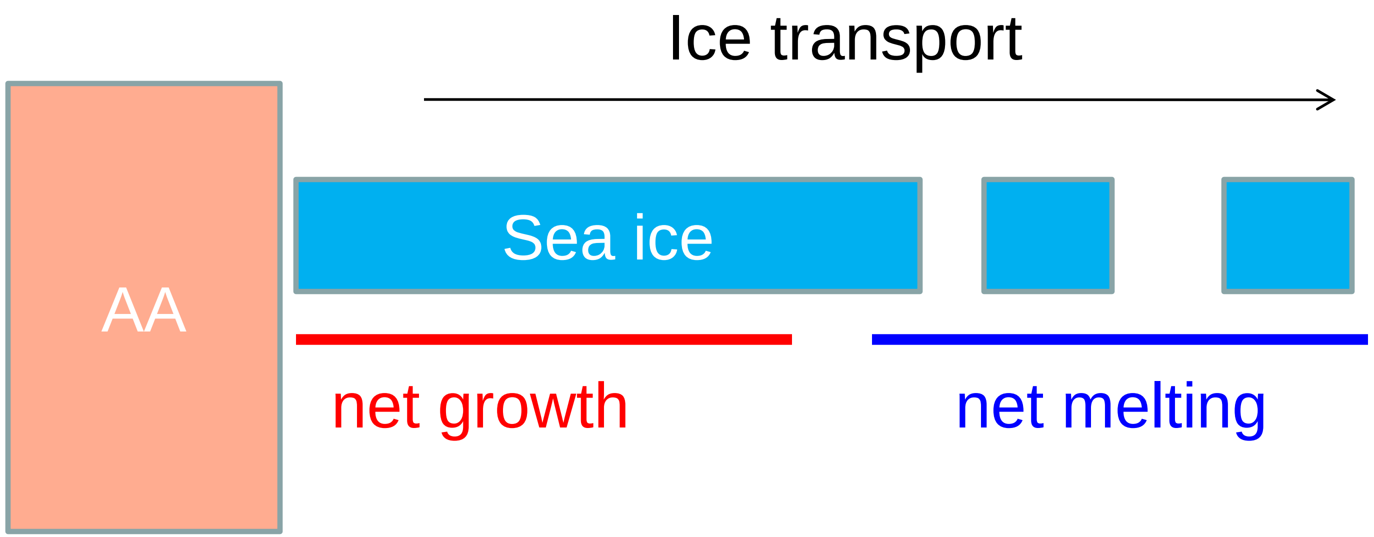
•Strengthened meridional overturning circulation brings CDW up at ~60S and warm surface waters down at ~50S
•Vertical eddy heat advection reinforces heating.
•Meridional heat transport anomalies are small.

Normal Sea Ice Mass Balance

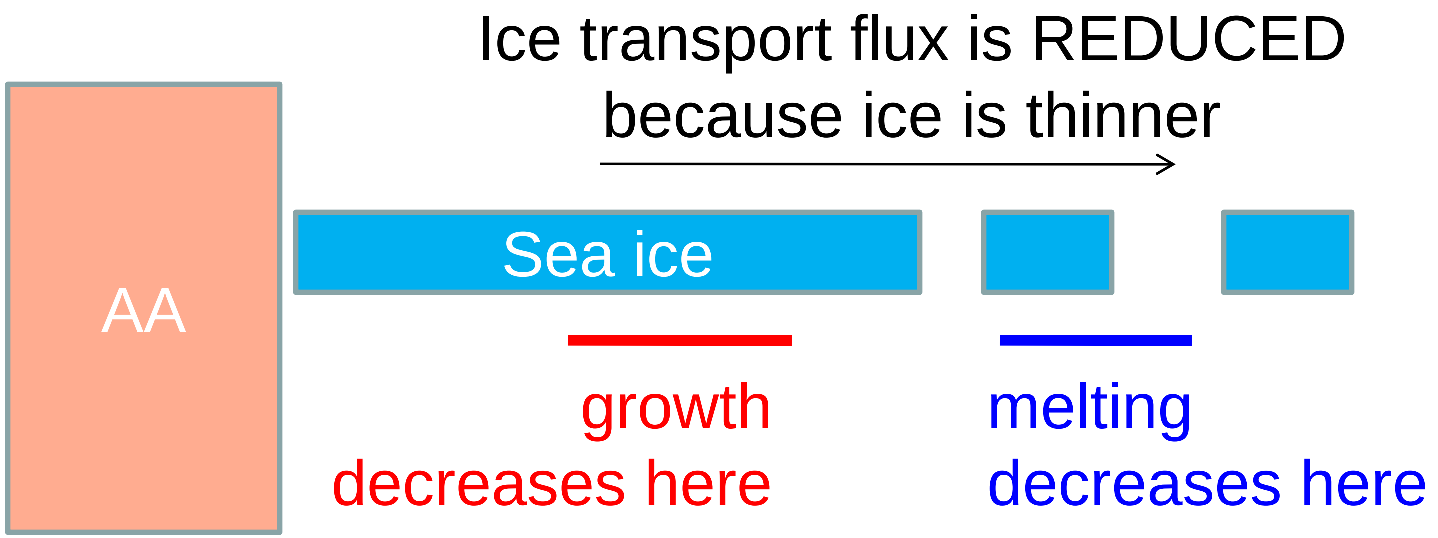




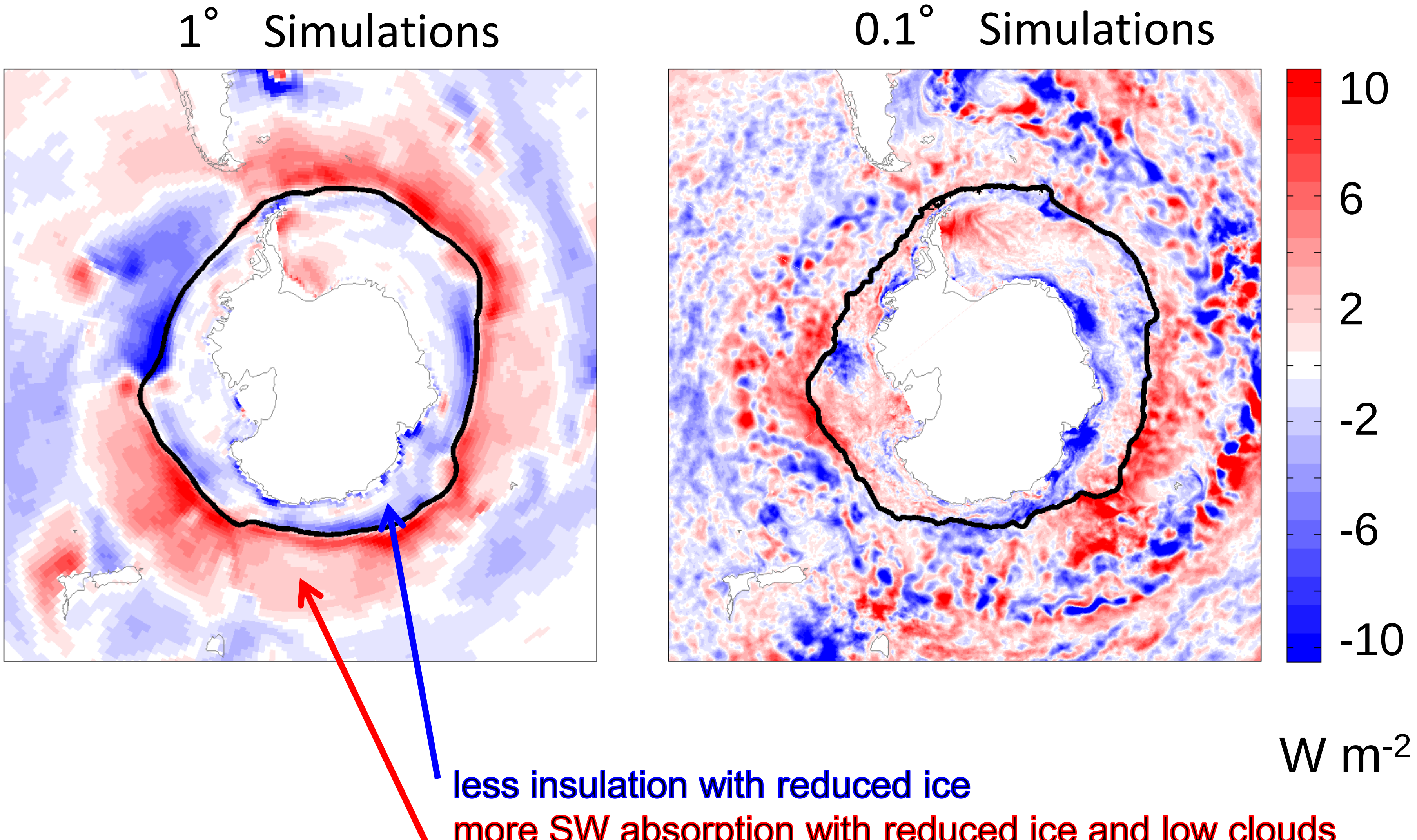
Normal Sea Ice Mass Balance



Sea Ice Mass Balance Response to ozone loss



Annual Mean Ocean Surface Heat Flux
Response to Ozone Loss, Reinforces Warming/Sea Ice Loss



Conclusions about quasi-equilibrium ozone depletion

The quasi-equilibrium response to ozone depletion is reduced Antarctic sea ice concentration and warmer surface air temperature (in agreement with Sigmond and Fyfe, 2010; Smith et al, 2012)

The sea ice response is dominated by thermodynamic changes, despite changes to ice motion

Below the surface, the low resolution ocean response is stronger. But on average the SST and sea ice response is about the same.

In the 21st century, ozone will recover and we can expect it to partially offset global warming effects on Antarctic sea ice loss, surface warming, and large-scale oceanic heat transport towards the shelves (Smith et al, 2012).

Question:
But why does sea ice expand when SAM is anomalously positive in a given year?

Causing some to assume that the forced response should be the same?

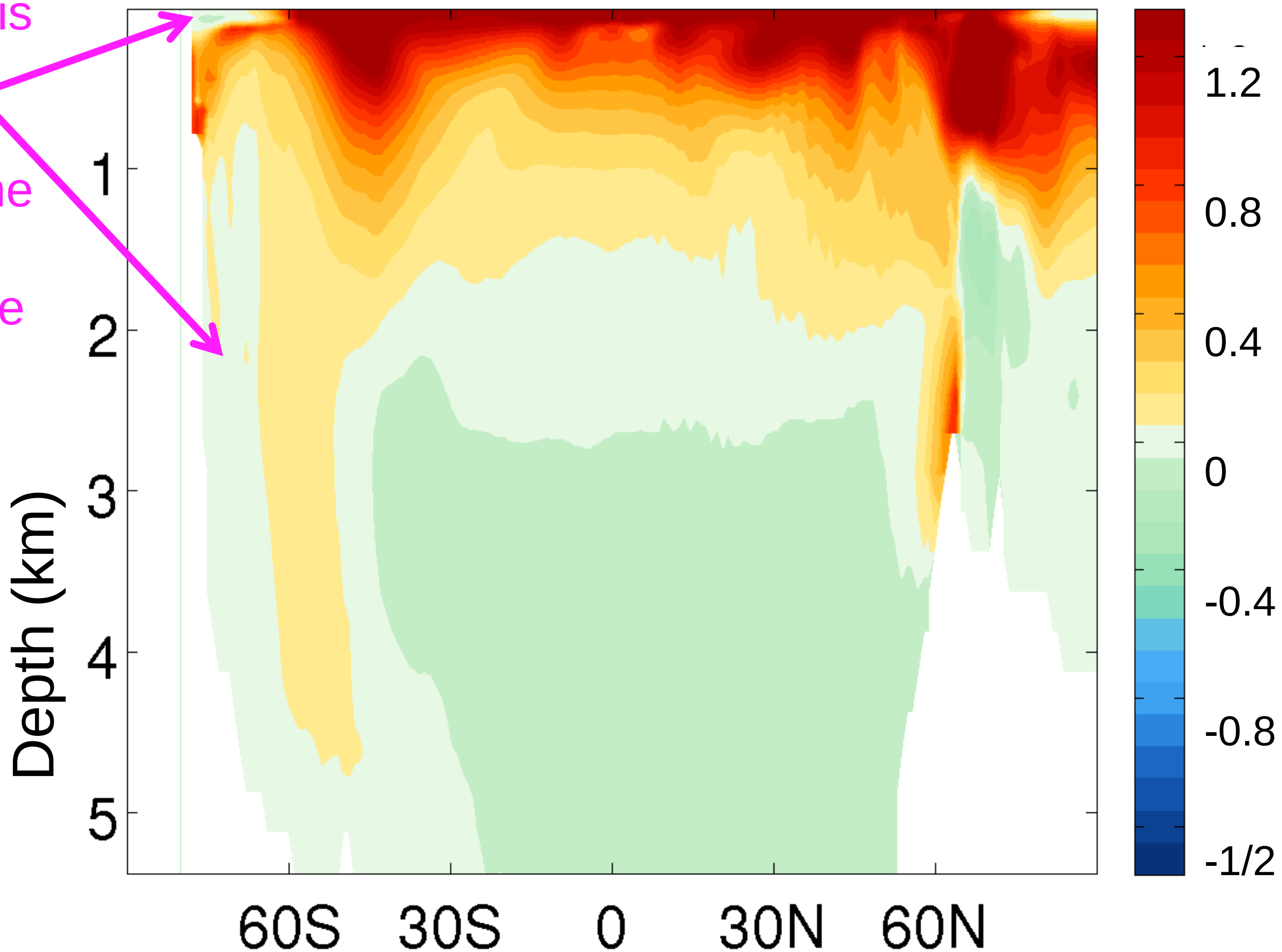
Answer:

There is a fast response to ozone depletion that is distinctly different from the slow response. This discrepancy has caused some to assume that the relationship based on interannual variability explains the trend.

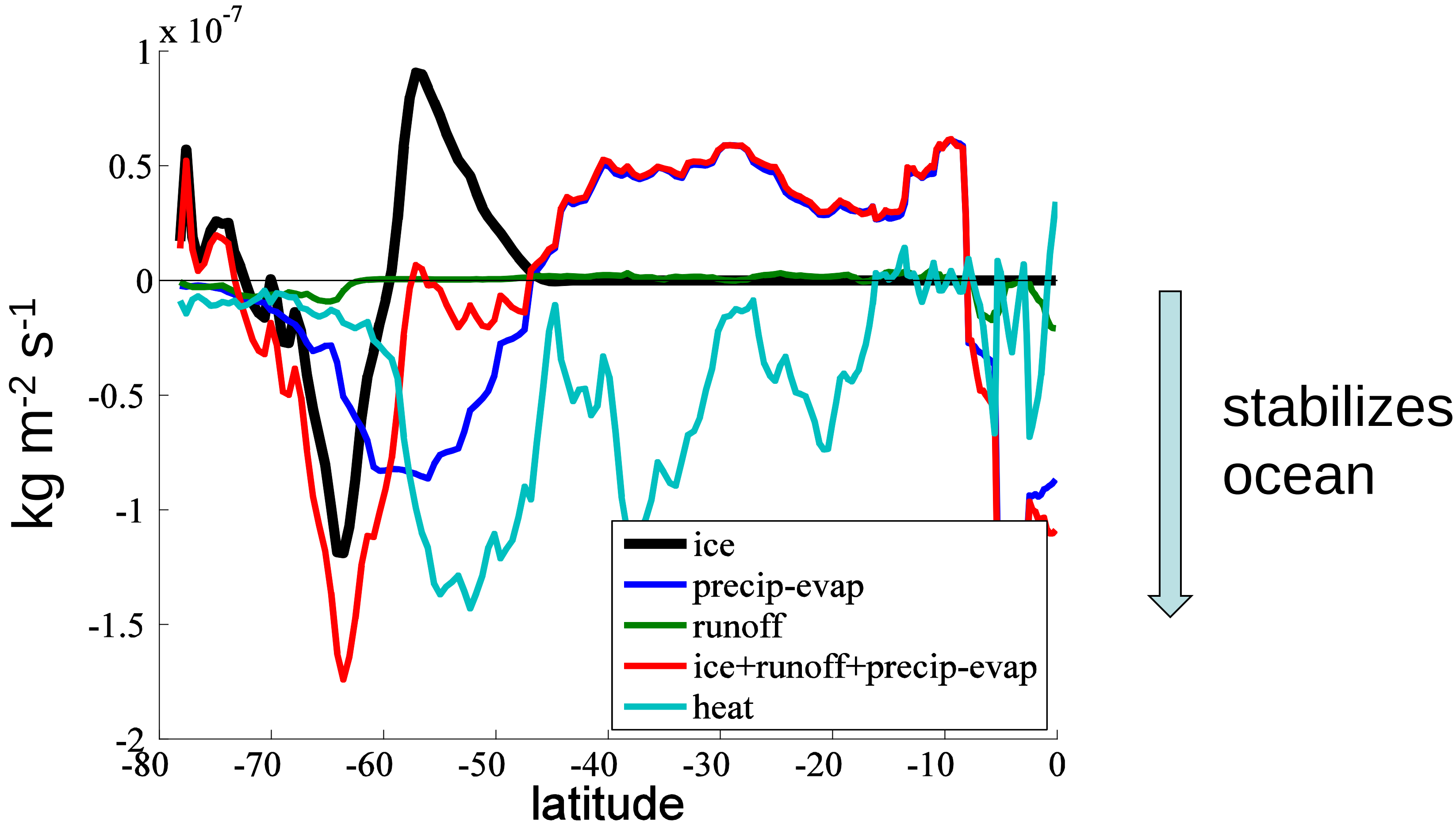
The fast response is simple Ekman, the slower response involves upwelling of CDW and enhanced mixing

CCSM4 Change in Ocean Temperature (Celsius) from rise of greenhouse gases in a half century

Why does this happen? Could enhancing the mechanism cause sea ice to expand?

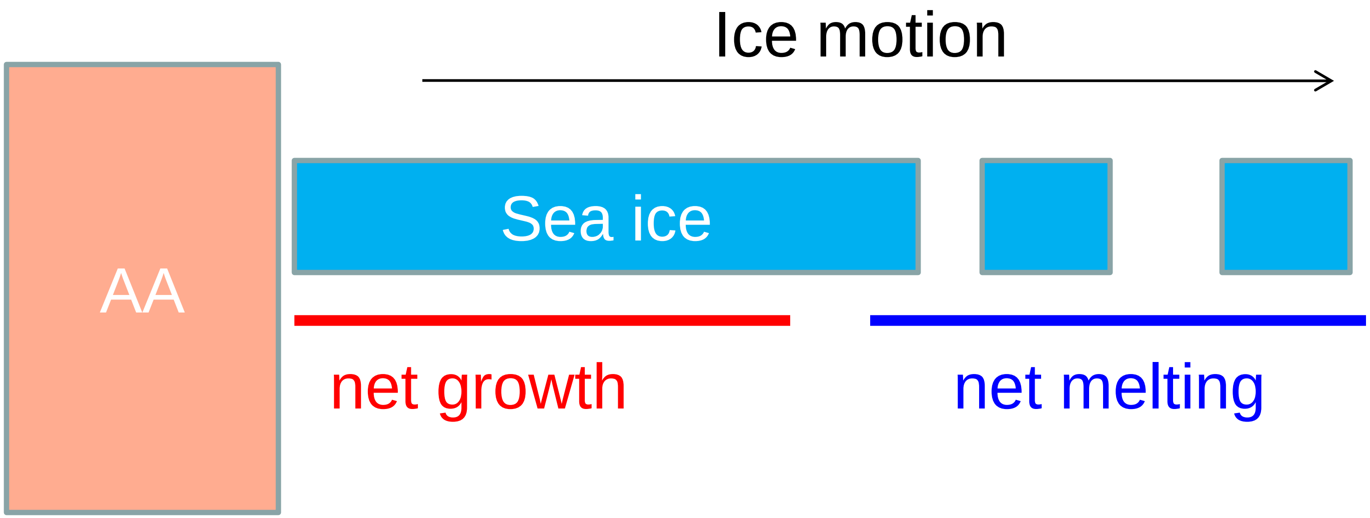


RESPONSE of surface density flux to raising CO2, weighted by ocean fraction along latitude circle

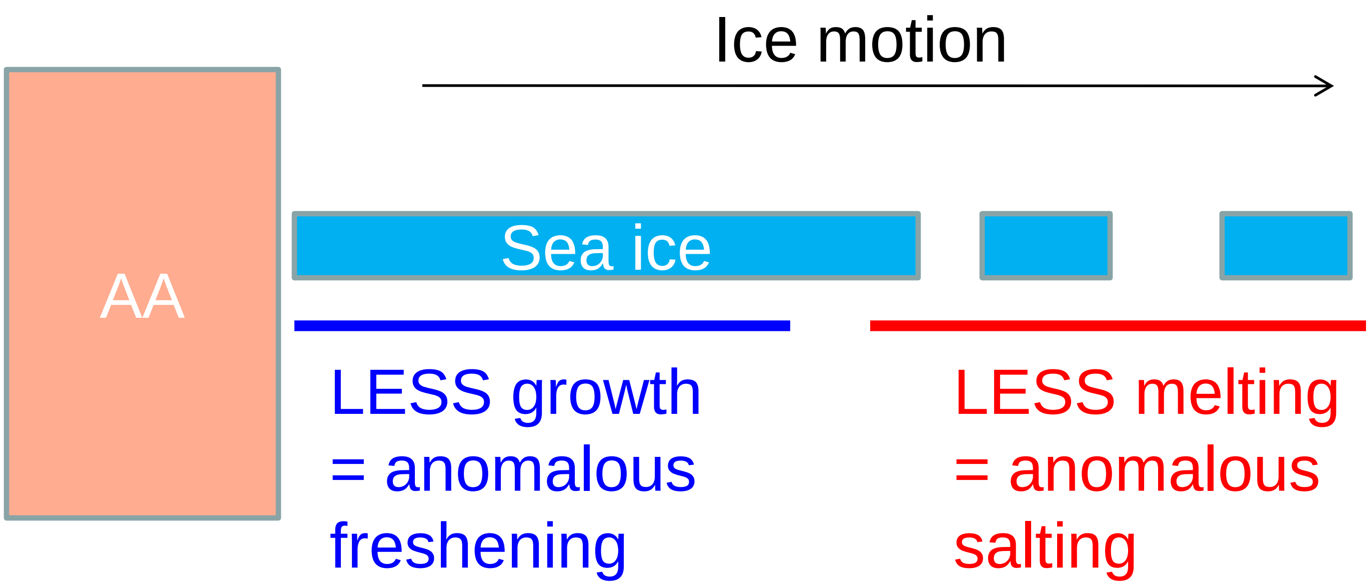


Kirkman and Bitz, 2011

Control Sea Ice Freshwater



Anomalous Sea Ice Freshwater from GHG



Ozone depletion (and increased winds in general) are not the cause of sea ice expansion

A freshwater source that is increasing in nature but missing in climate models could be key to stabilizing the Southern Ocean and causing the surface under the sea ice to cool and the sea ice to expand