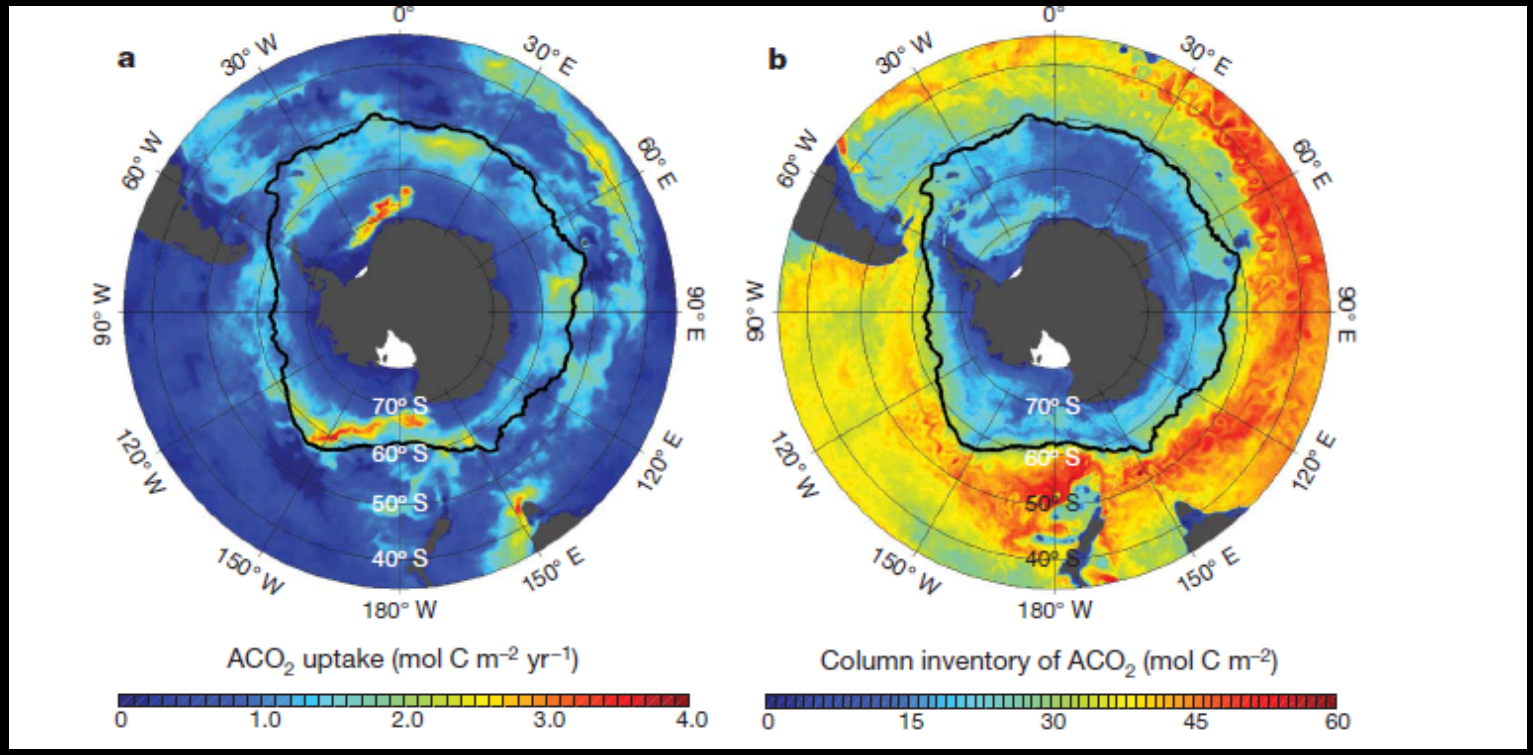
What does ^{14}C of DIC tell about changes in Southern Ocean overturning in the last 3 decades?

Colm Sweeney

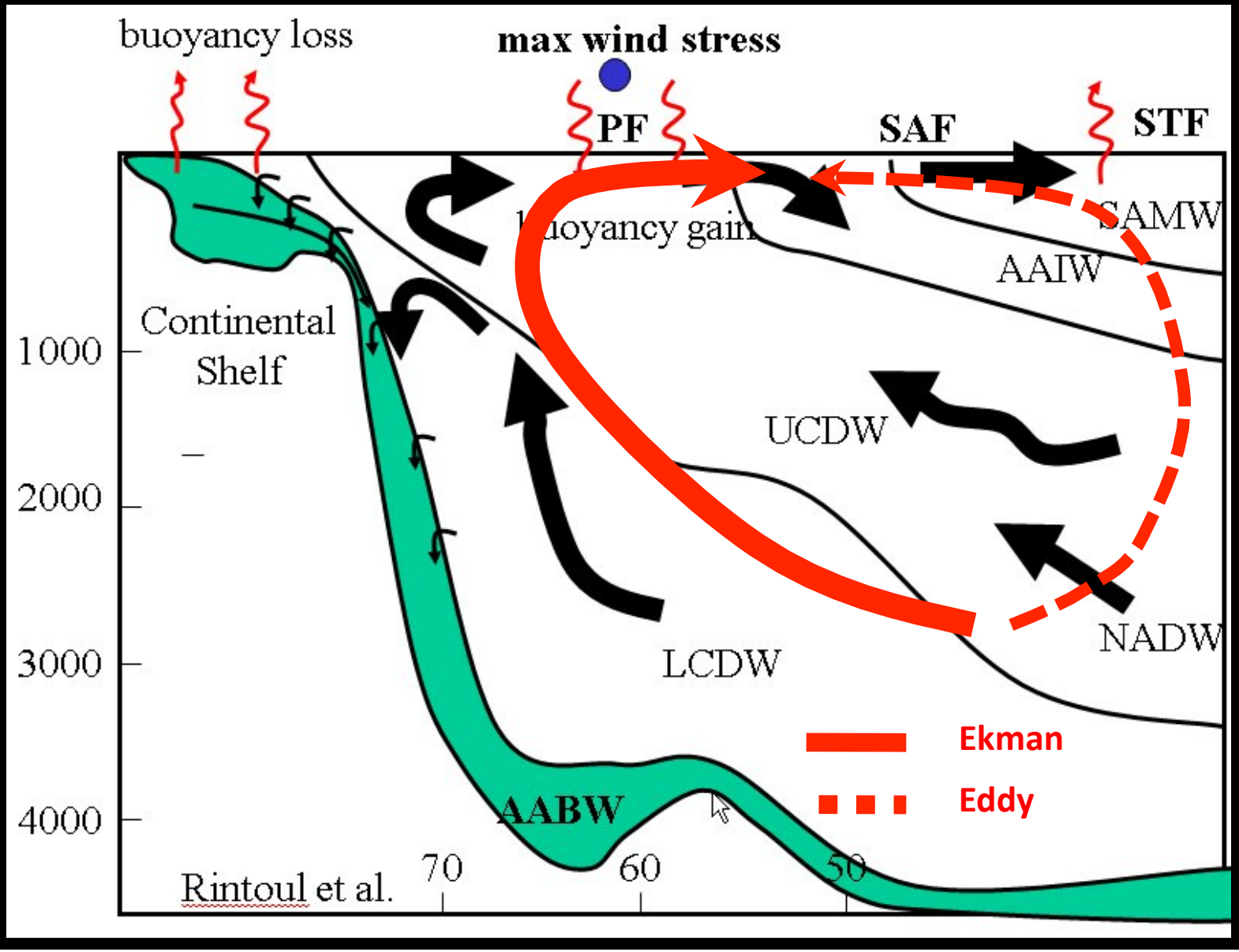
Contributions from:
Tom Guilderson
Taro Takahashi Tim Newberger
Stewart Sutherland
Nikki Lovenduski
Corinne Le Quere
Keith Rogers Sara Mikaloff-Fletcher

Transport of Anthropogenic Carbon

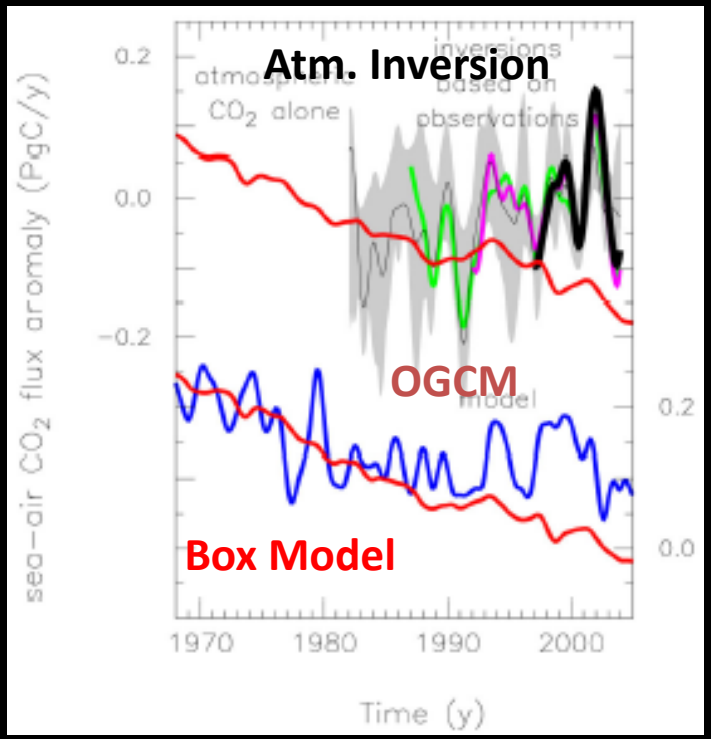


Ito et al 2010

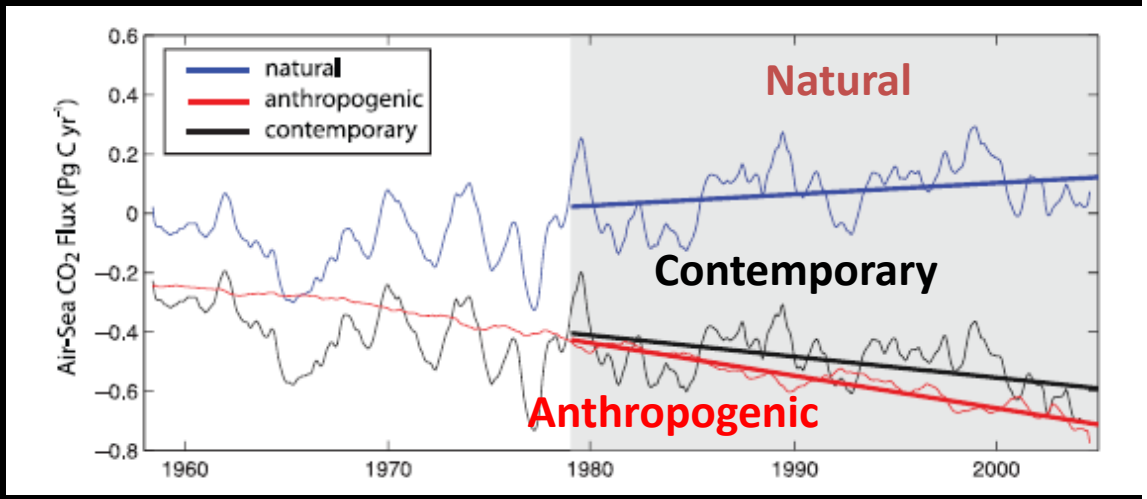
Meridional Overturning Circulation (MOC)



Increases in MOC cause decreases CO_2 sink in Southern Ocean



Le Quere 2007



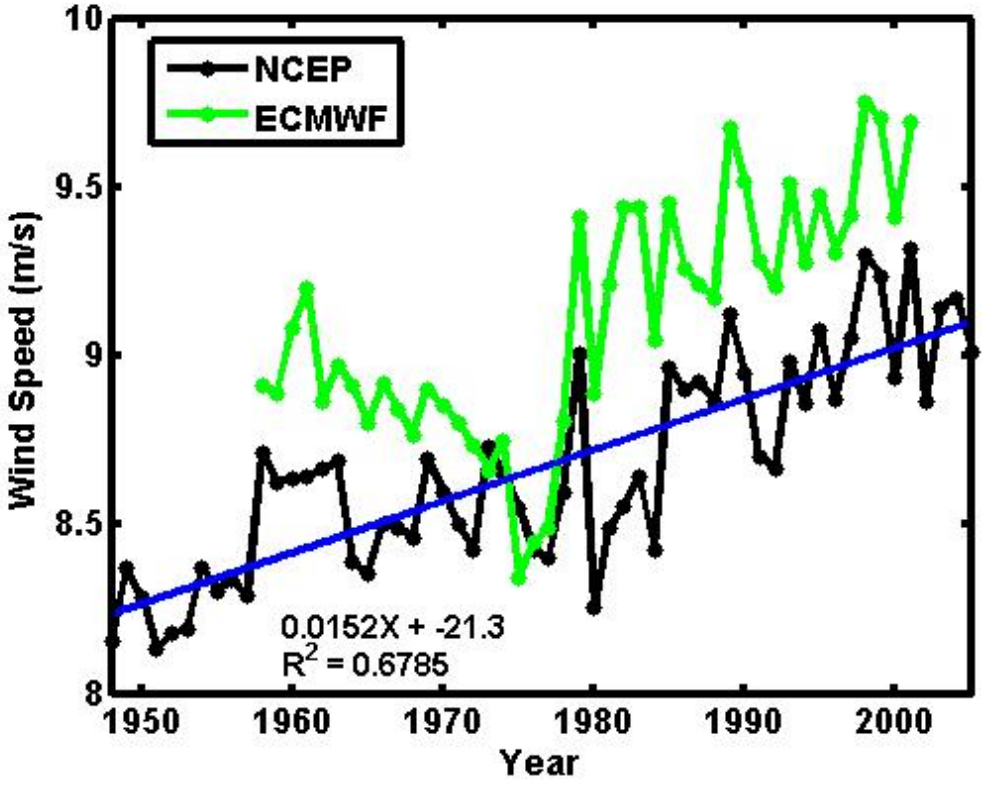
Lovenduski 2008

Natural carbon flux is not in steady-state:

-MOC has brought CO_2 and nutrients to the surface.

-Biological productivity is not responding

-Net decrease in ocean sink (0.01 Pg/yr)

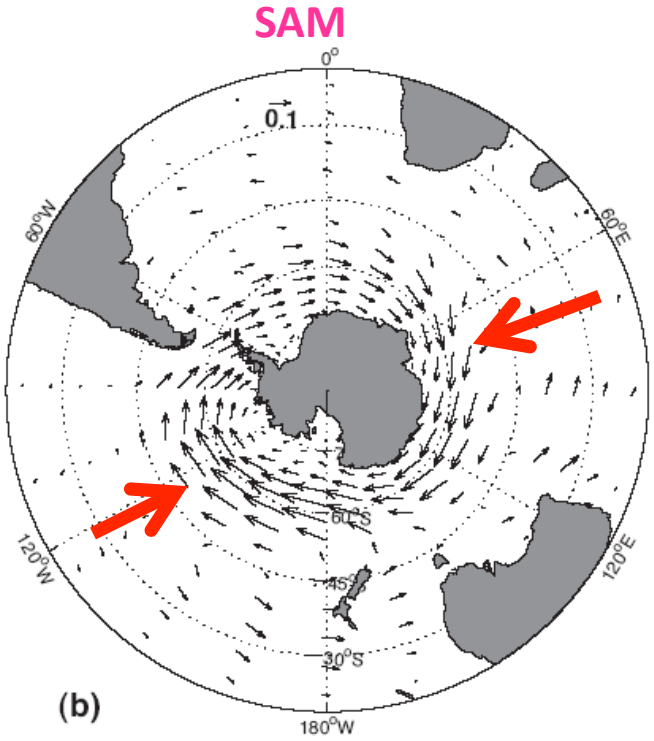


Wind Stress Maximum

- Low pressure anomalies over Antarctic force wind stress maximum towards south pole.

Wind Stress

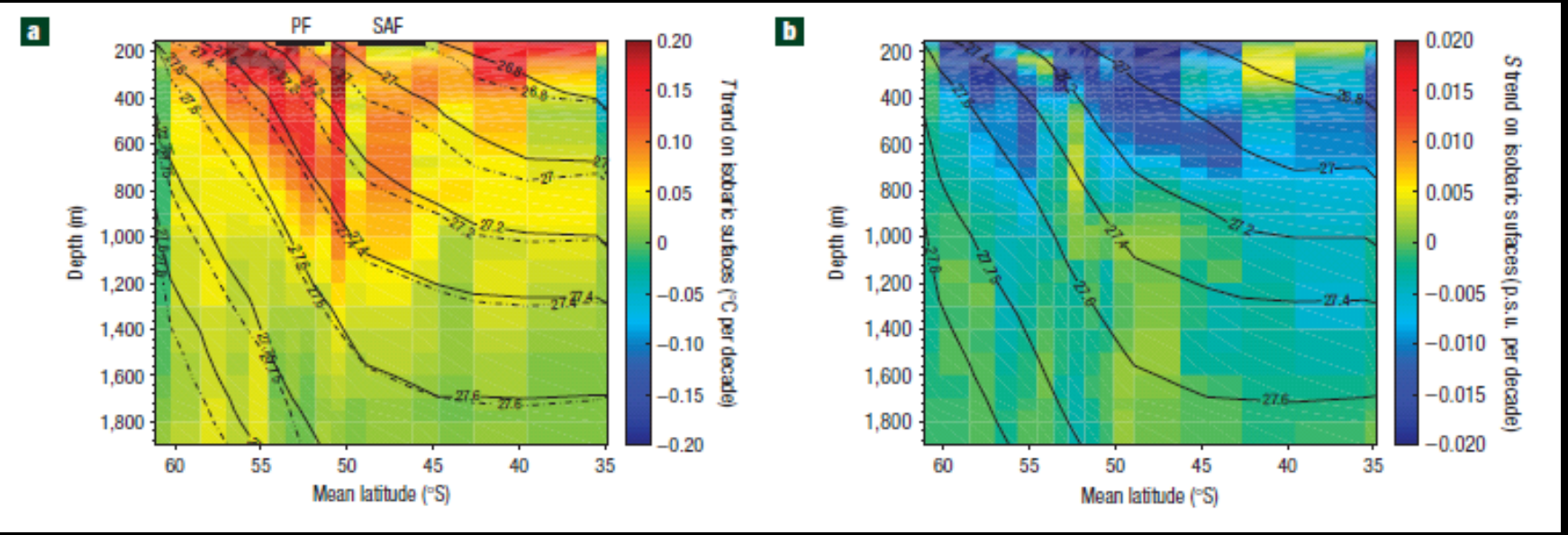
~15% increase in wind speeds over the last 50 years



Temperature and Salinity Observations

Temperature

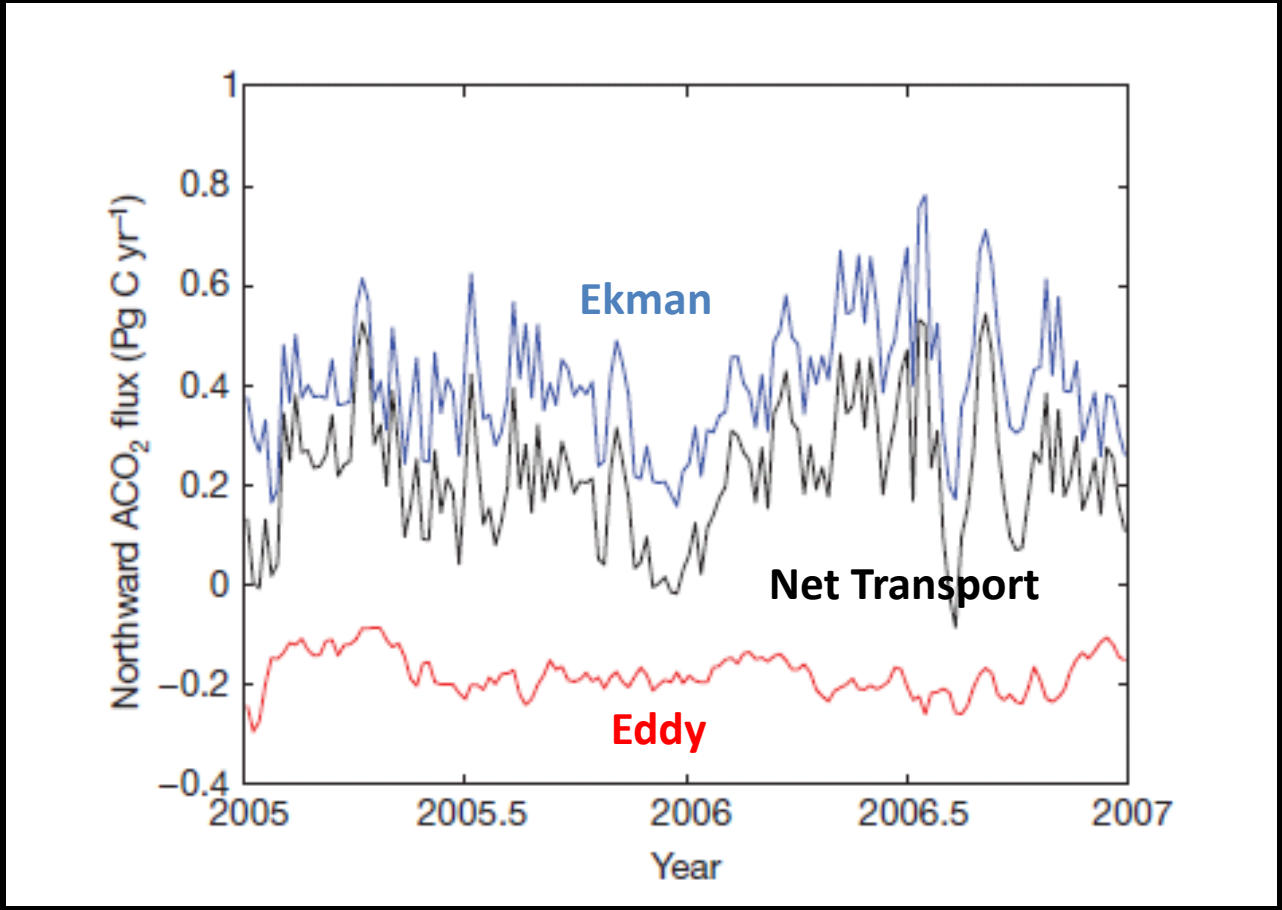
Salinity



- Significant trends towards warming and freshening between 30S and 60S
- No change in isopycnal slopes

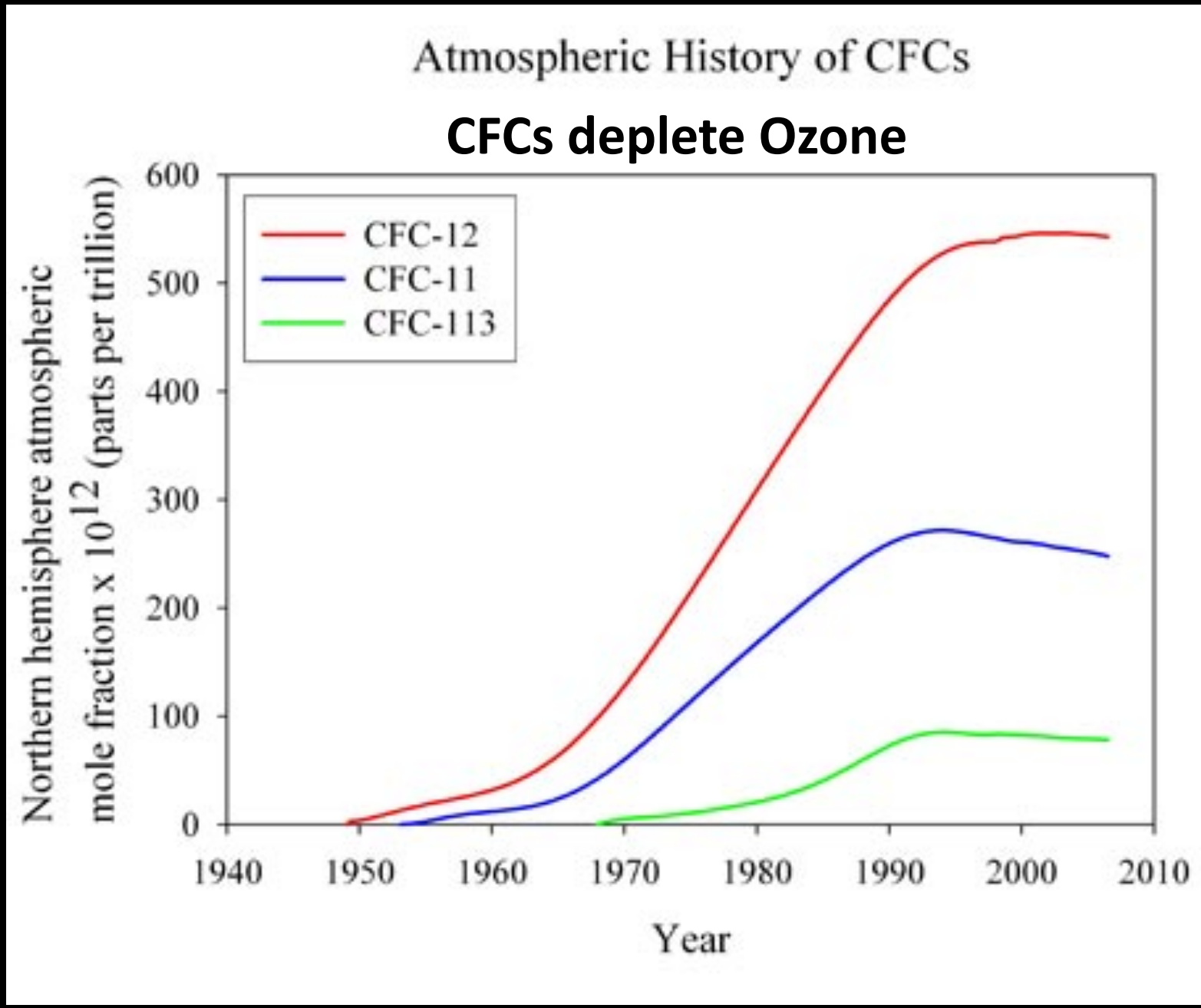
Boning et al 2008

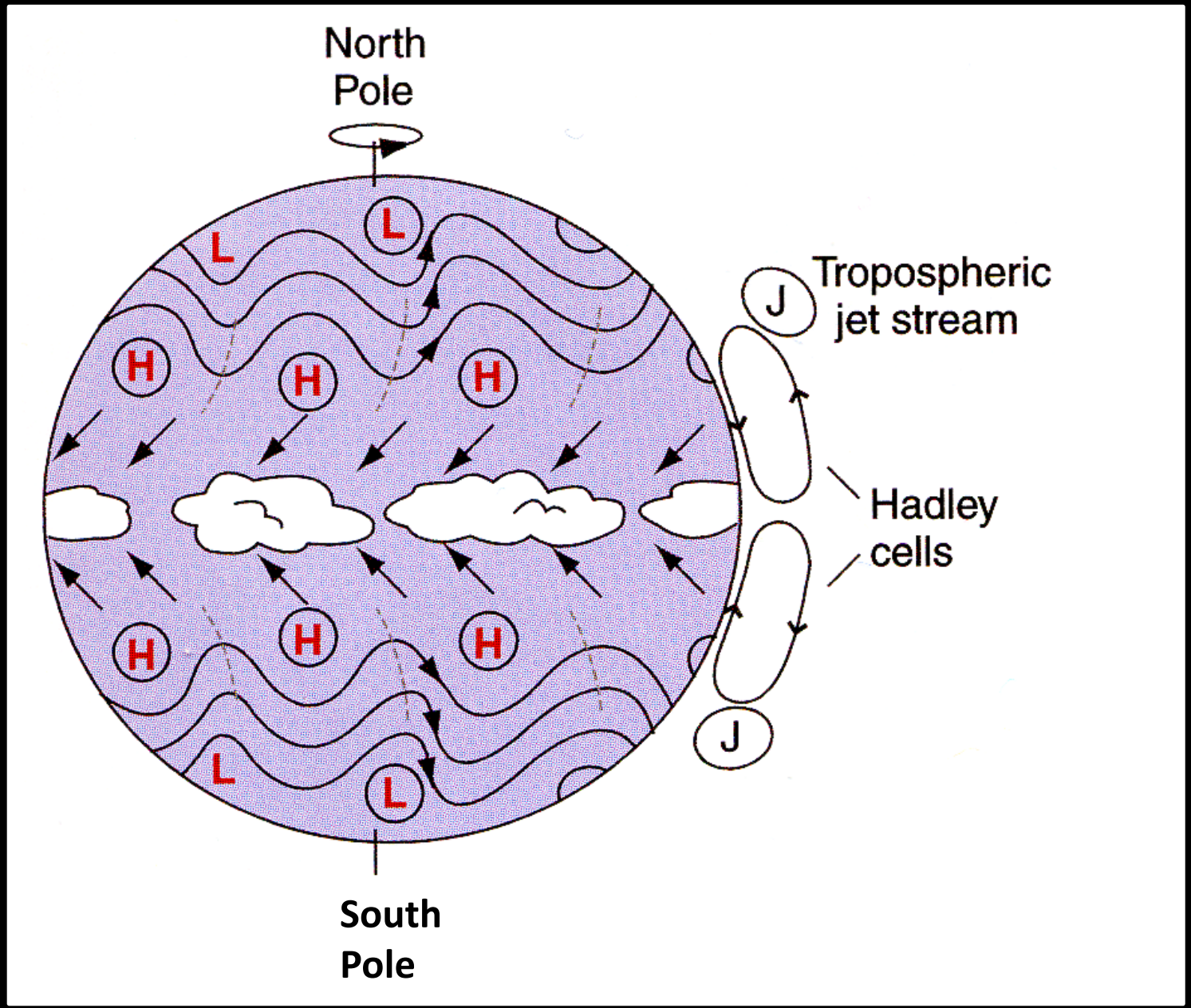
Northward Transport

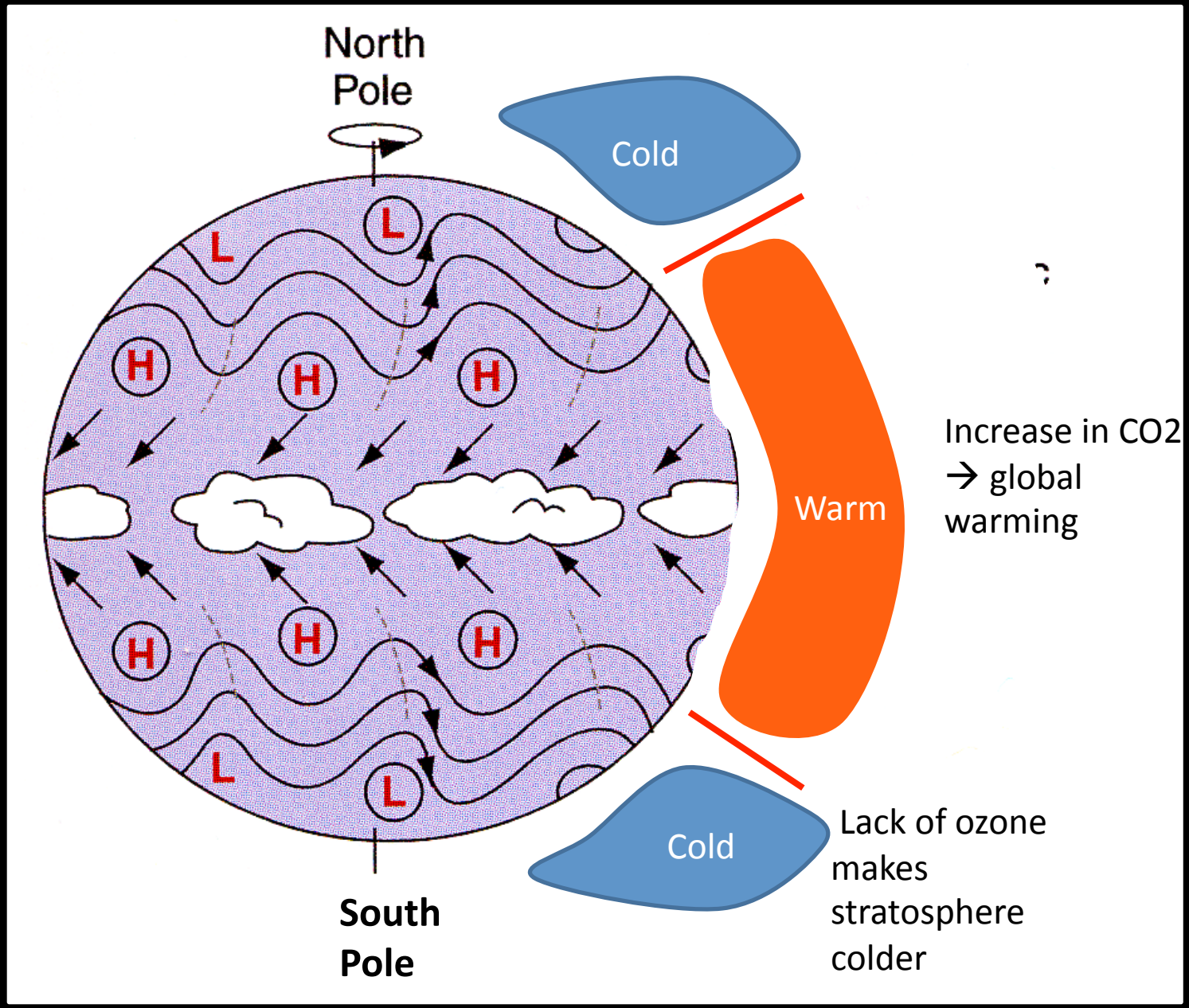


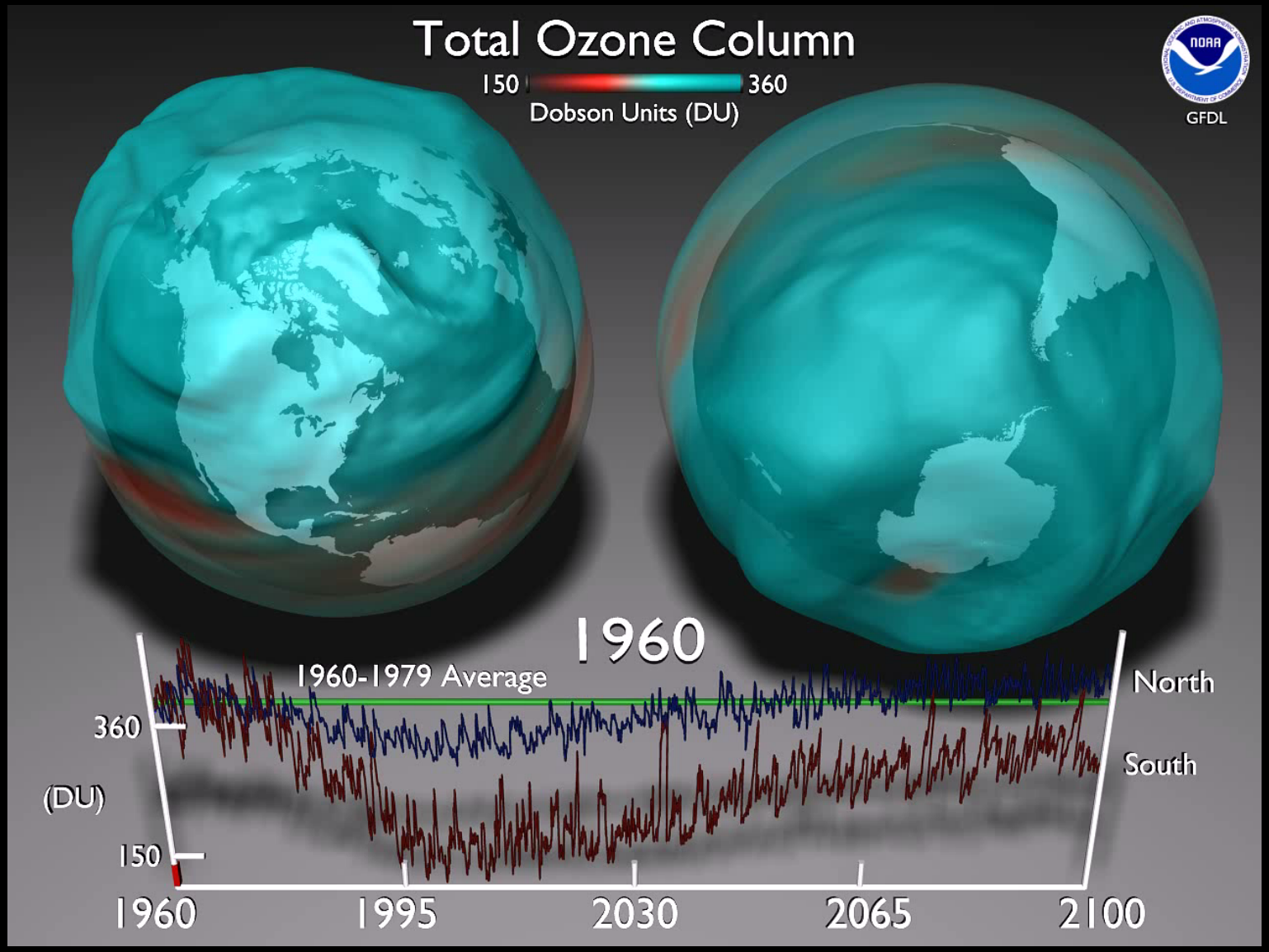
Ito et al 2010

CFCs deplete Ozone

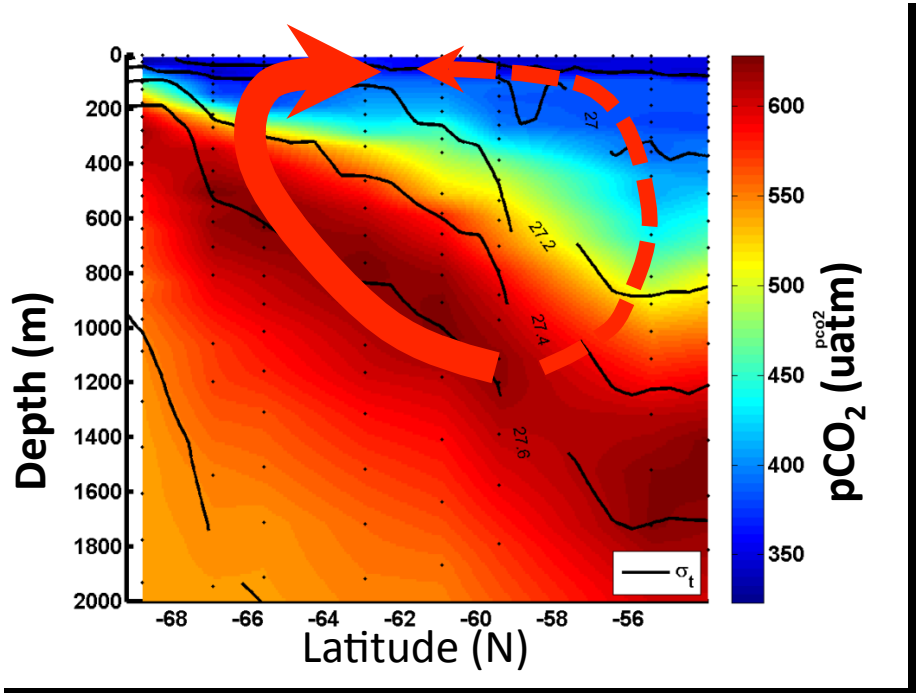


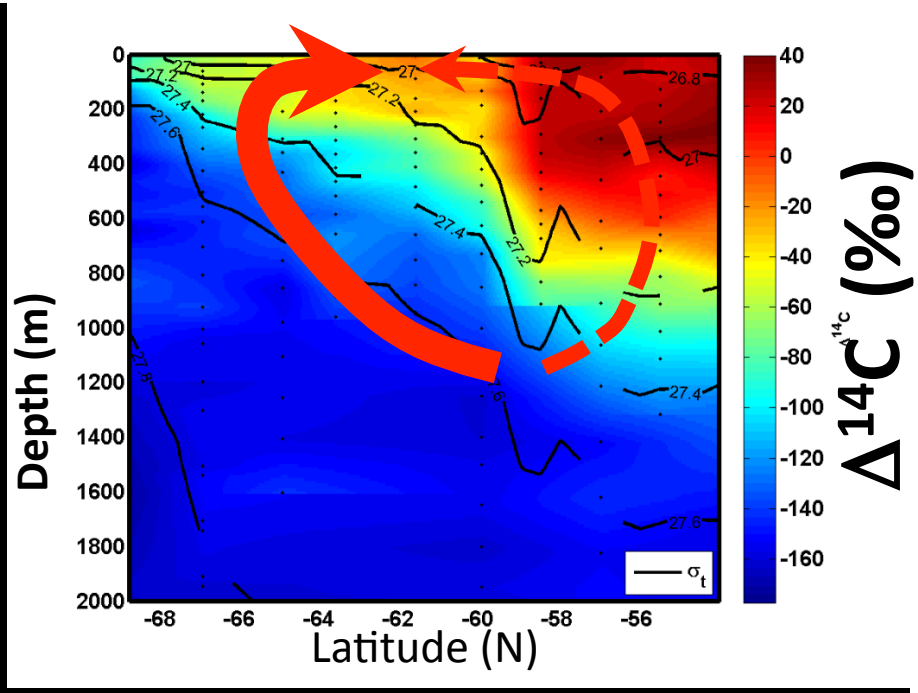

North
Pole
L
L
H
H
H
H
H
H
L
L
J
Tropospheric
jet stream
Hadley
cells
J
South
Pole


North Pole
Cold
L
L
H
H
H
H
H
H
L
L
Warm
Increase in CO2 → global warming
Cold
Lack of ozone makes stratosphere colder
South Pole

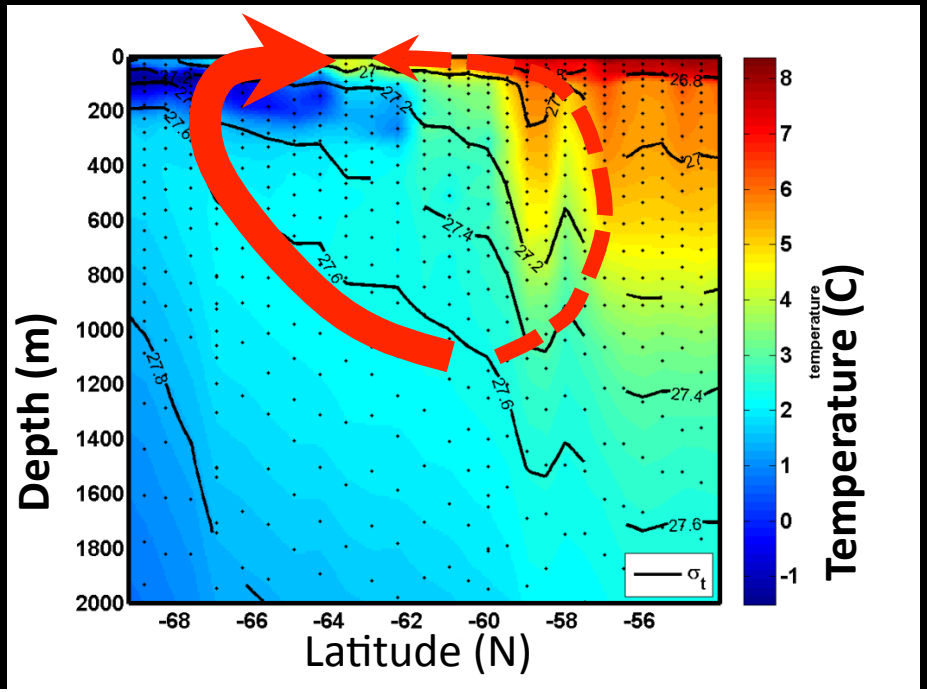


John Austin: The animation shows the evolution of northern and southern hemisphere ozone as simulated in the GFDL coupled chemistry-climate model.





pCO_2 @ insitu T



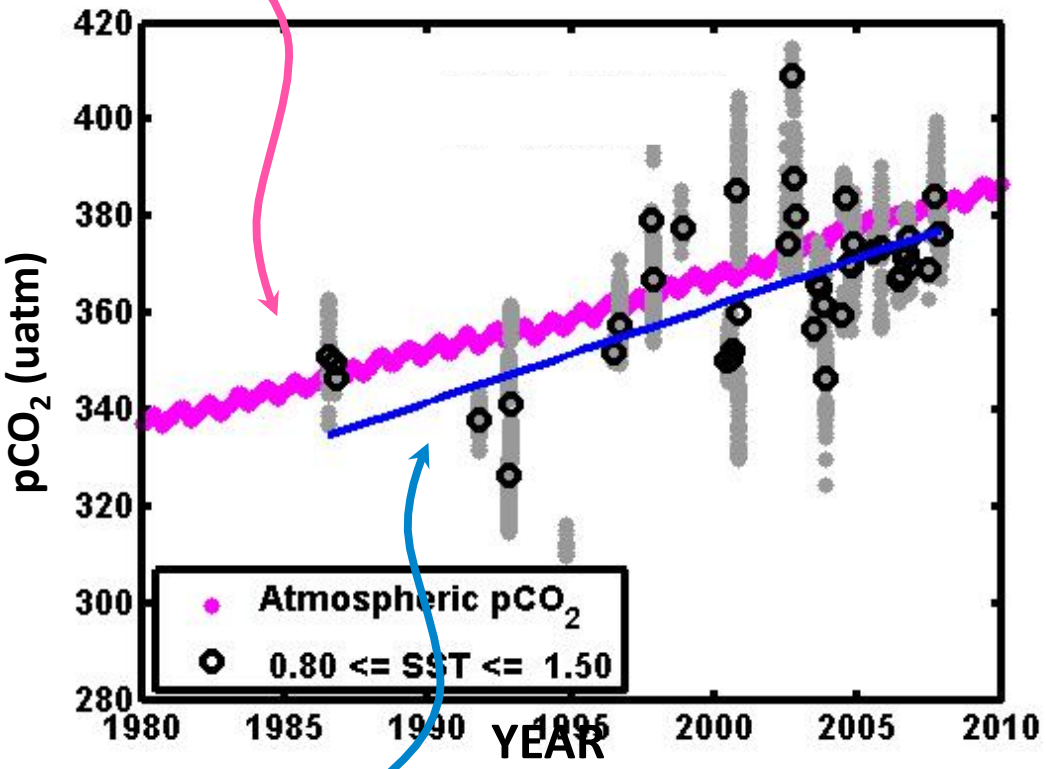
$\Delta^{14}C$

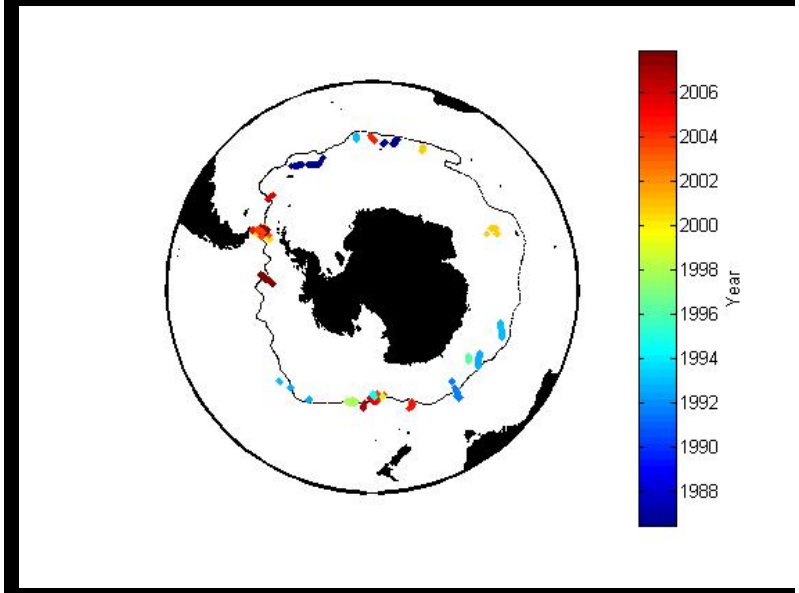
WOCE P17
Eastern Pacific

Ekman
Eddy

pCO_2 Wintertime Trend Analysis

Atmospheric Trend = 1.63 uatm/yr





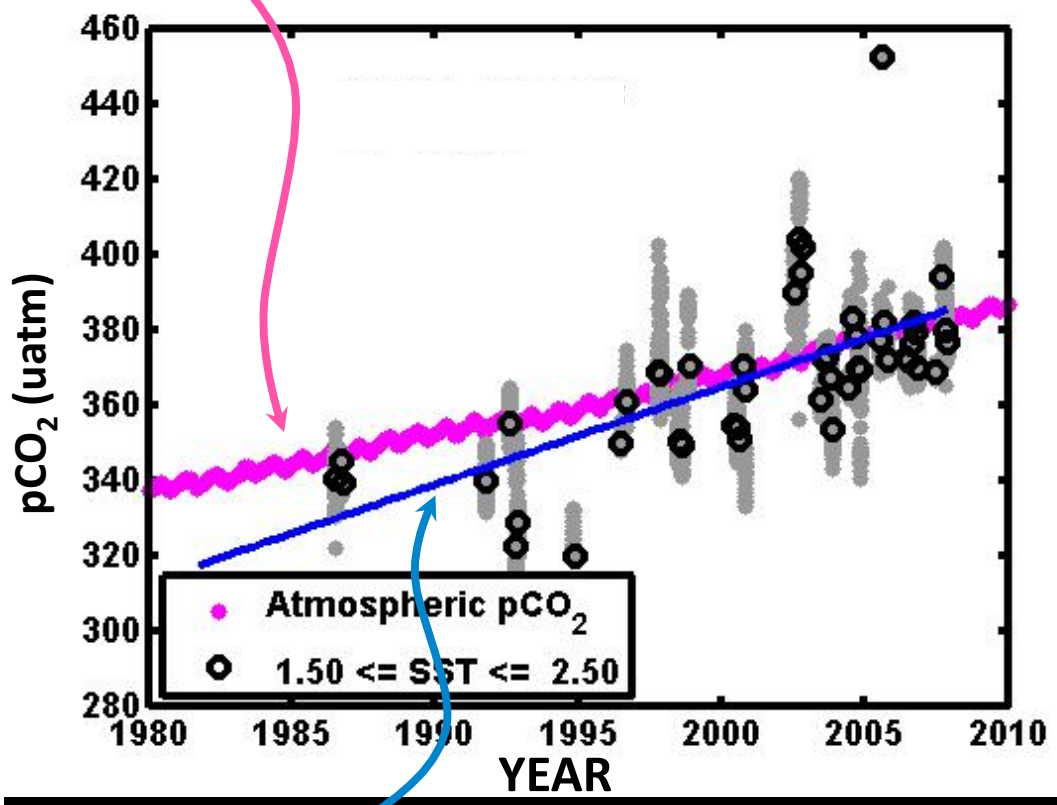
0.8C < SST < 1.5C wintertime

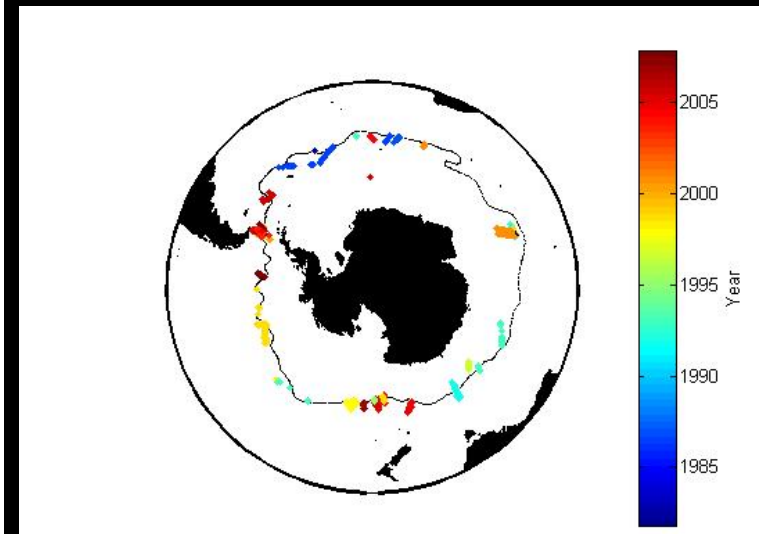
Ocean Trend = 1.98 ± 0.38 uatm/yr

Takahashi et al., 2009

pCO_2 Wintertime Trend Analysis

Atmospheric Trend = 1.63 uatm/yr



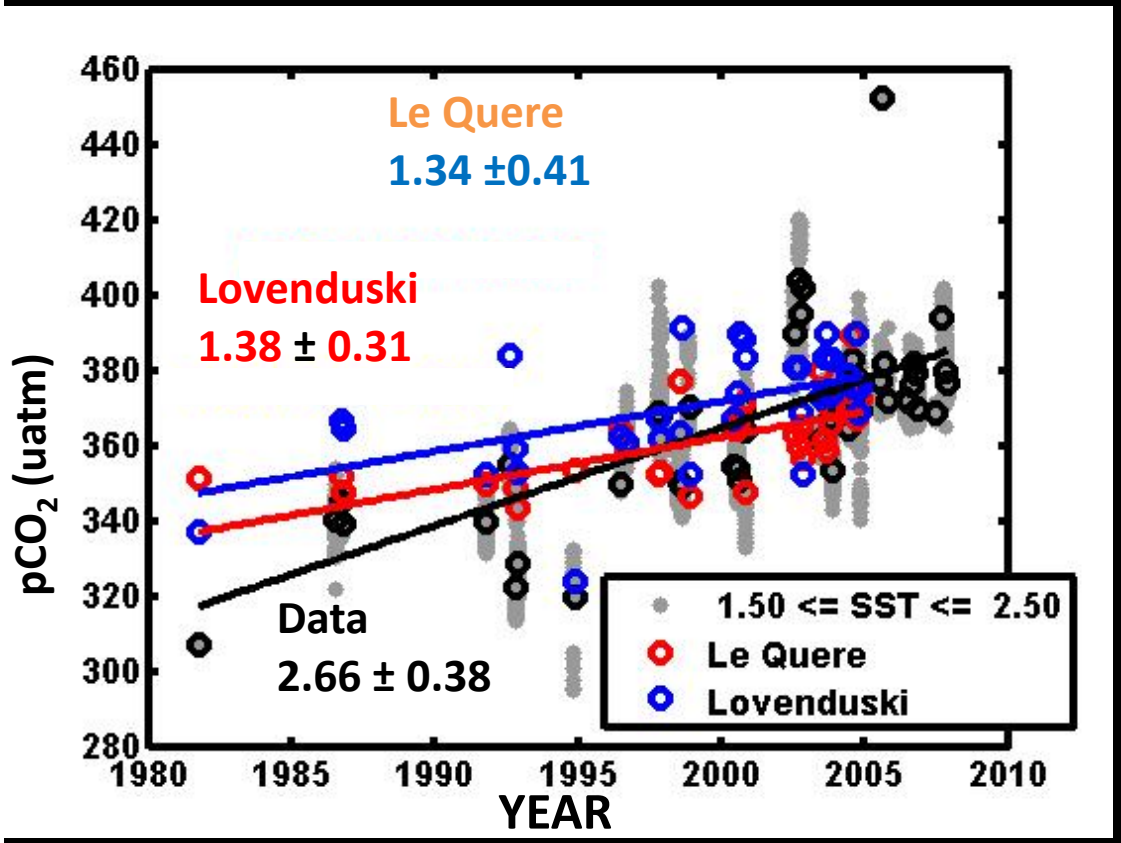


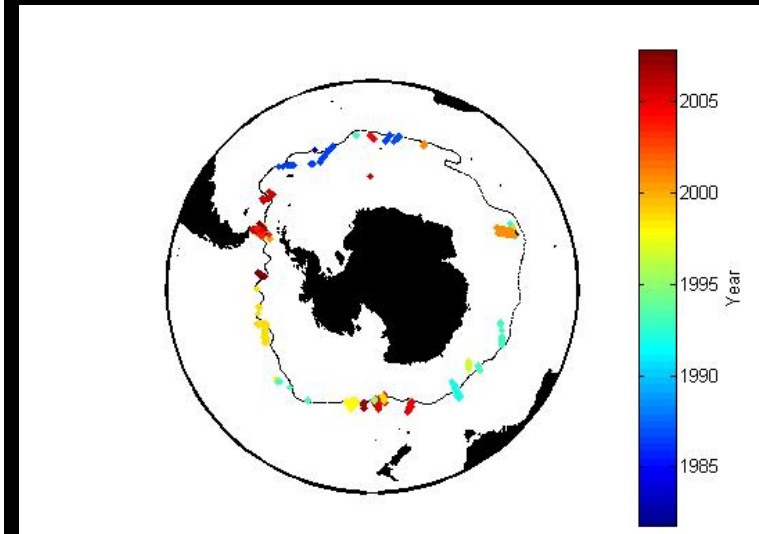
1.5C < SST < 2.5C wintertime

Ocean Trend = 2.66 ± 0.38 uatm/yr

Takahashi et al., 2009

Comparing pCO_2 trend with Models





1.5C < SST < 2.5C wintertime

Models are significantly underestimating rise in CO_2

Takahashi et al., 2009

Trend in surface water pCO_2

SST	Takahashi 2009	LeQuere 2007		Lovenduski 2008	
		Takahashi	All regions	Takahashi	All regions
0.8 to 1.5	1.98 ± 0.44	1.50 ± 0.36	1.86 ± 0.06	1.30± 0.46	1.35± 0.09
1.5 – 2.5	2.59 ± 0.44	1.38 ± 0.31	1.81 ± 0.05	1.34 ± 0.47	1.39 ± 0.09
2.5 – 3.5	2.95 ± 0.45	1.58 ± 0.37	1.76 ± 0.05	2.63 ± 0.56	1.45 ± 0.09
3.5 – 4.5	2.78 ± 0.68	1.83 ± 0.31	1.72 ± 0.05	2.16 ± 0.42	1.45 ± 0.09
4.5 – 5.5	2.01 ± 0.41	2.45 ± 0.32	1.72 ± 0.05	1.67 ± 0.45	1.51 ± 0.09
5.5 – 6.5	1.39 ± 0.43	2.38 ± 0.54	1.74 ± 0.06	1.77 ± 0.50	1.52 ± 0.09

Mean Atmospheric Trend: 1.63 µatm/year

Models are significantly underestimating rise in surface water CO_2 at SSTs between 1.5C and 4.5C

Trend in surface water pCO_2

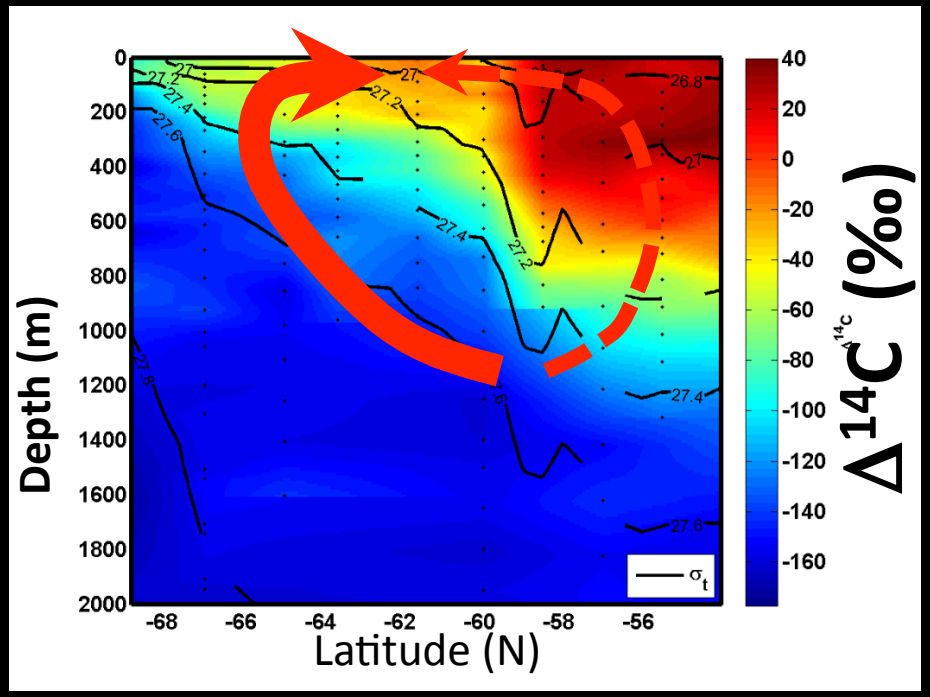
SST	Takahashi 2008	LeQuere 2007	Lovenduski 2008
0.8 to 1.5	1.82 ± 0.39	1.86 ± 0.06	1.35± 0.09
1.5 – 2.5	2.66 ± 0.38	1.81 ± 0.05	1.39 ± 0.09
2.5 – 3.5	2.80 ± 0.39	1.76 ± 0.05	1.45 ± 0.09
3.5 – 4.5	2.61 ± 0.58	1.72 ± 0.05	1.45 ± 0.09
4.5 – 5.5	1.85 ± 0.35	1.72 ± 0.05	1.51 ± 0.09
5.5 – 6.5	1.18 ± 0.40	1.74 ± 0.06	1.52 ± 0.09

Mean Atmospheric Trend: 1.63 uatm/year

Models are significantly underestimating rise in surface water CO_2 at SSTs between 1.5C and 5.5C

Why is surface pCO2 rising so fast?

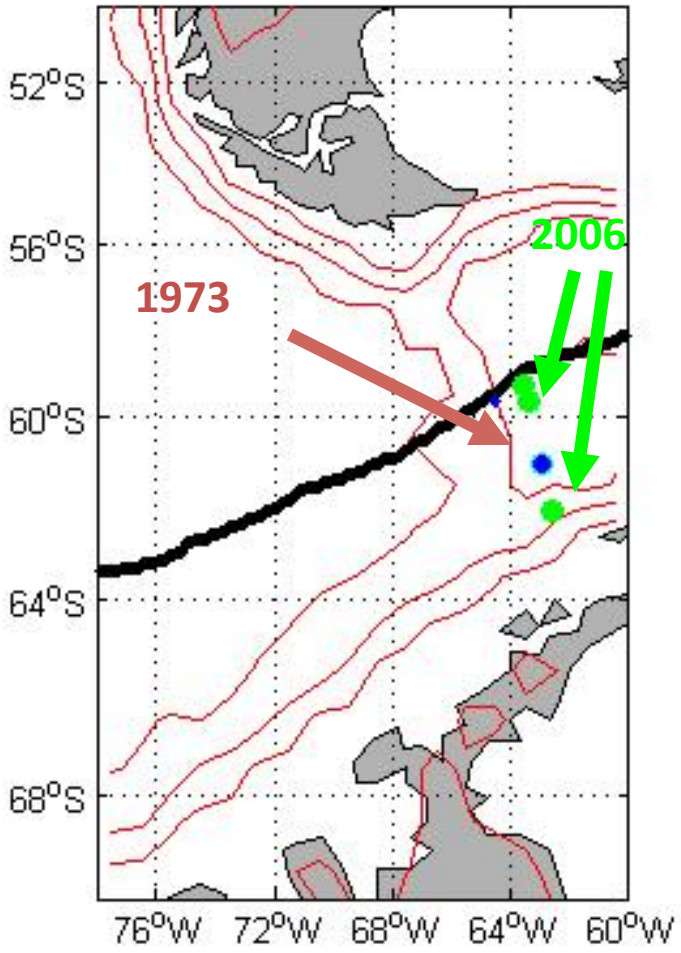
- Increase in temperature?
- Decrease in biological uptake?
- Increase in Overturning circulation?

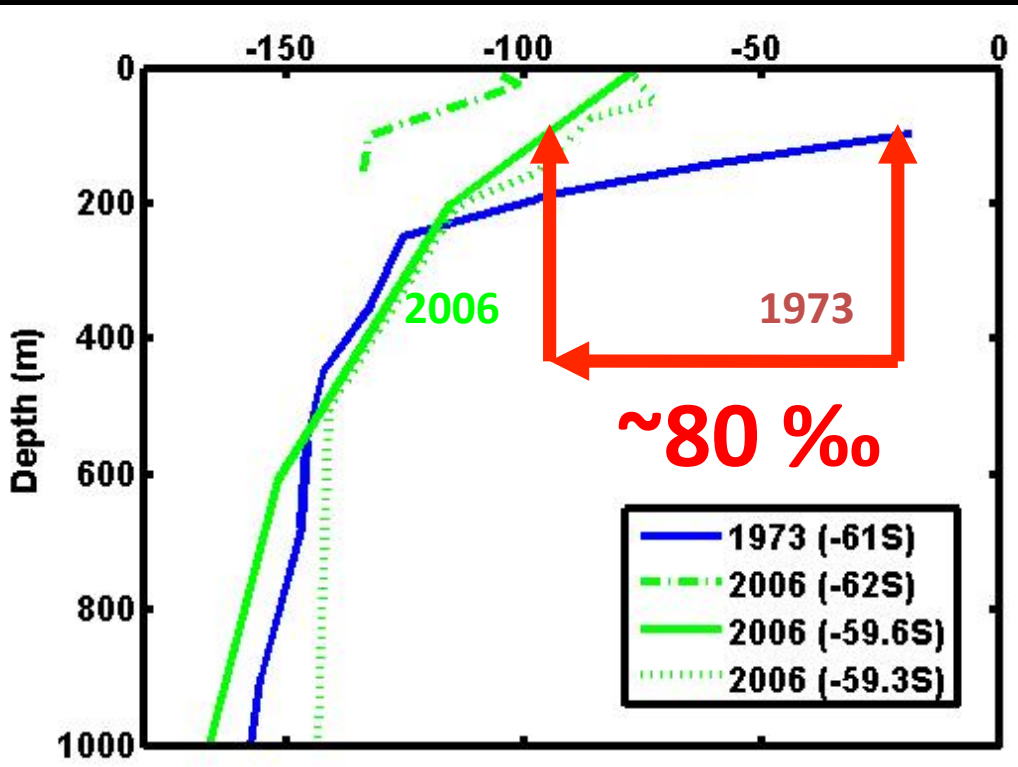


Change in Surface water $\Delta^{14}C$

1973 - 2006

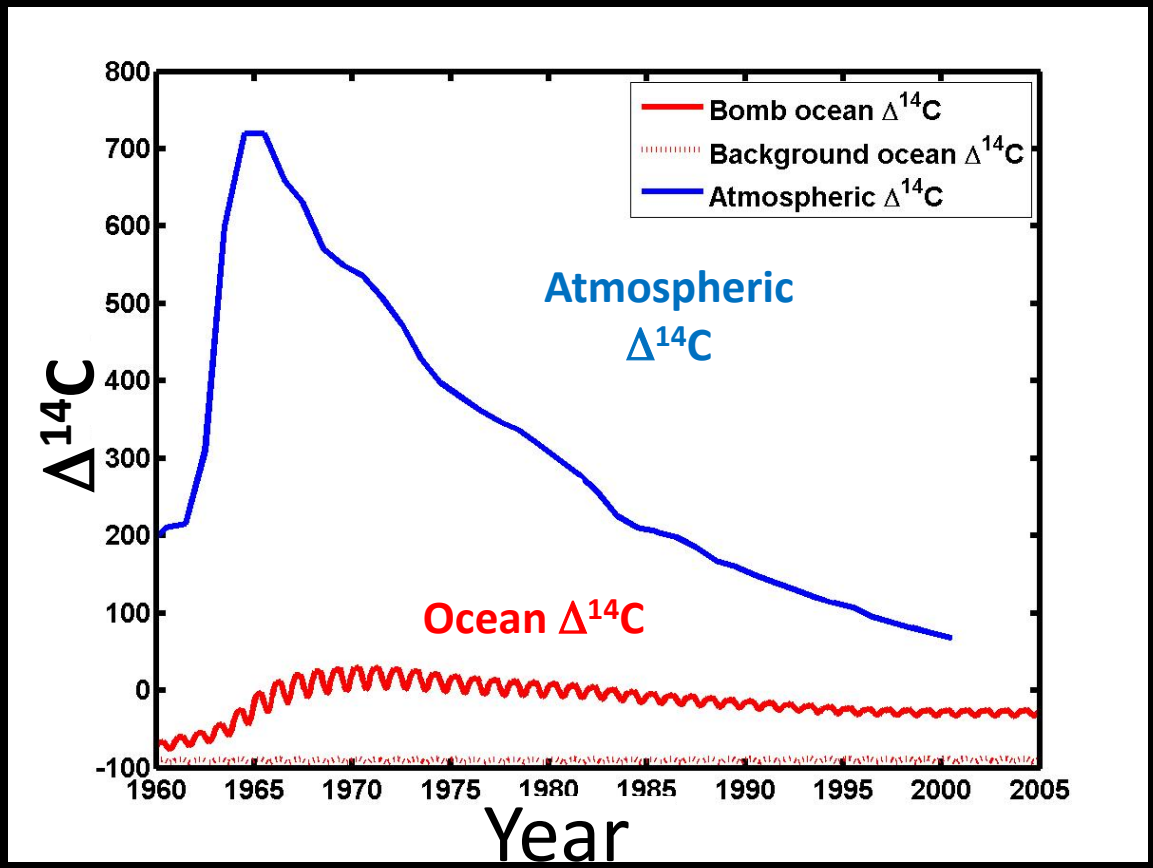
$\Delta^{14}C$ (‰)





Comparison of surface water $\Delta^{14}C$ 1973 - 2006 suggests change of 80‰

Gas Exchange for $\Delta^{14}C$

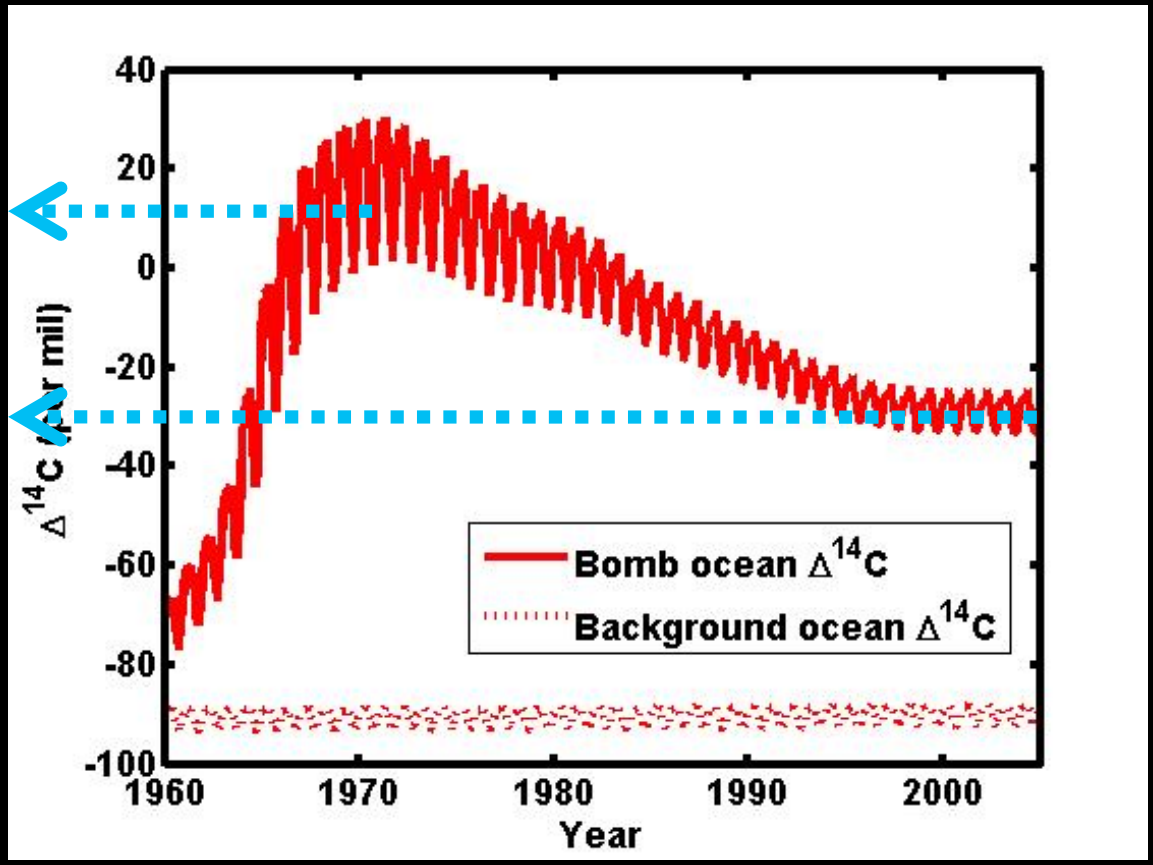


MOM4 Ocean GCM run with climatological forcing $\Delta^{14}C$

Courtesy of Rogers and Mikaloff-Fletcher

Gas Exchange for $\Delta^{14}C$

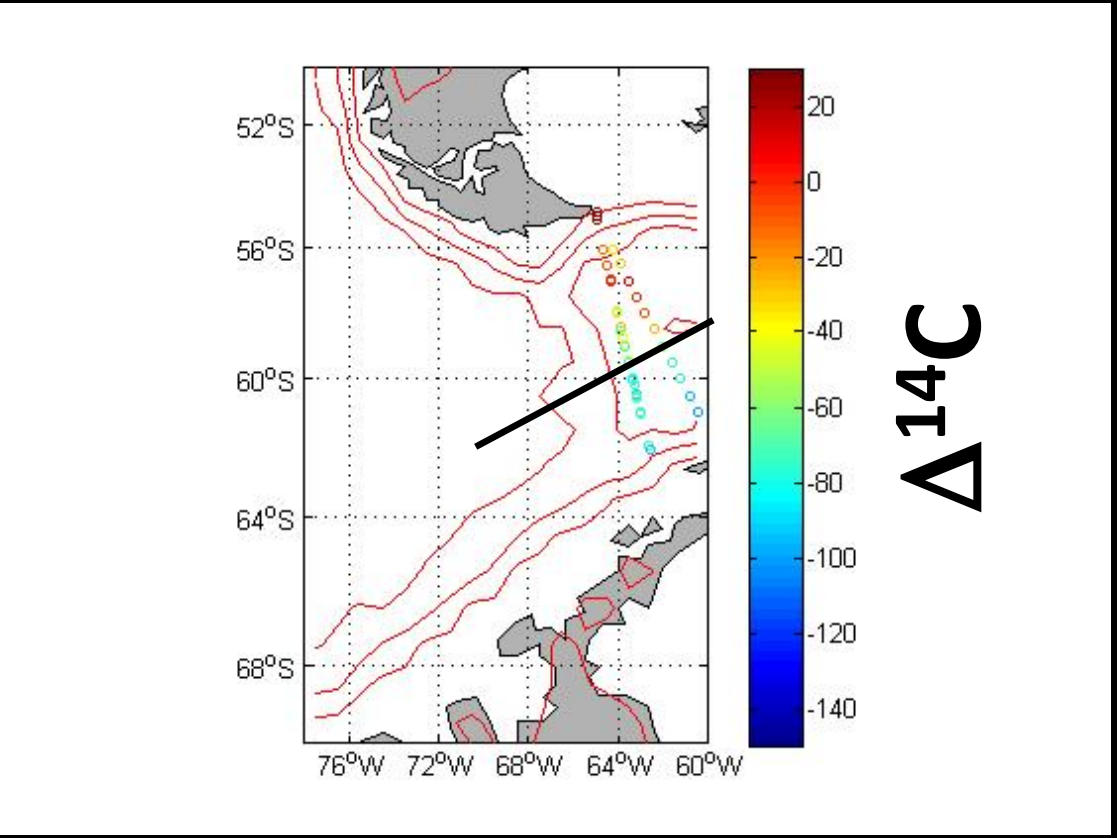
~50 ‰



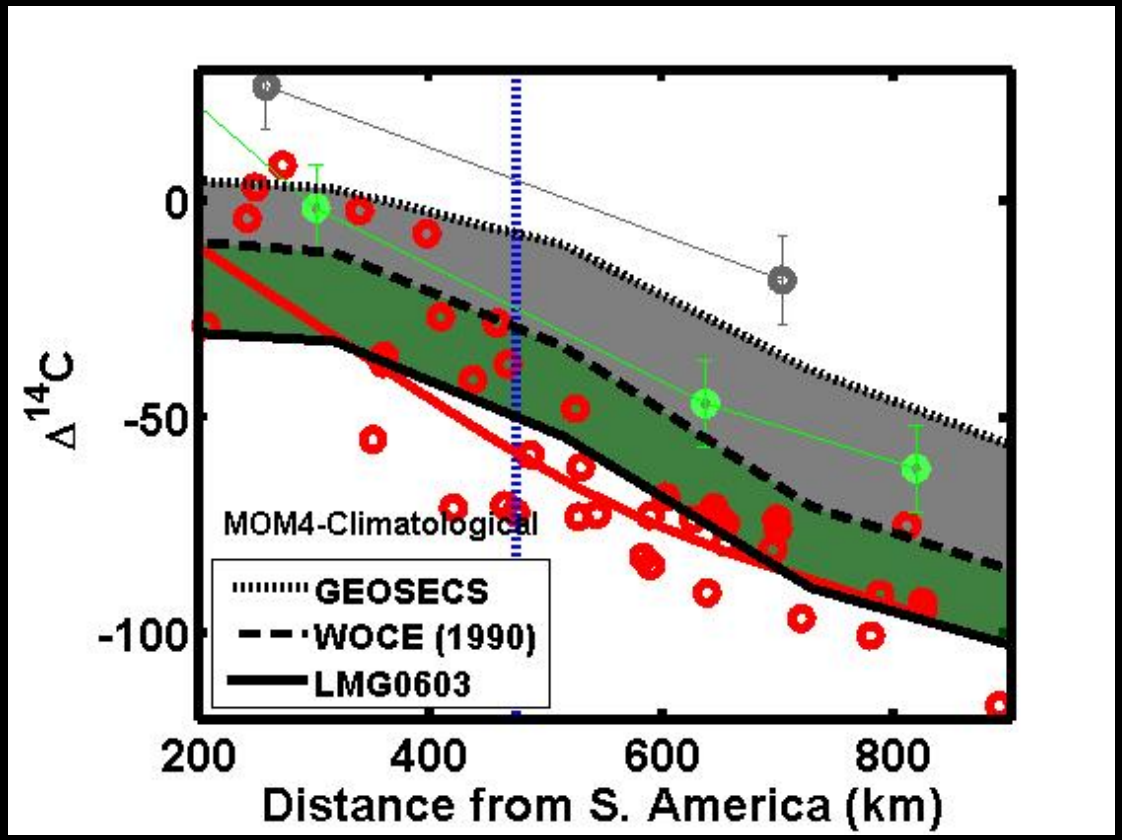
MOM4 runs shows only 49‰ change due to bomb ^{14}C pulse

Courtesy of Joe Majkut

Recent Surface measurements



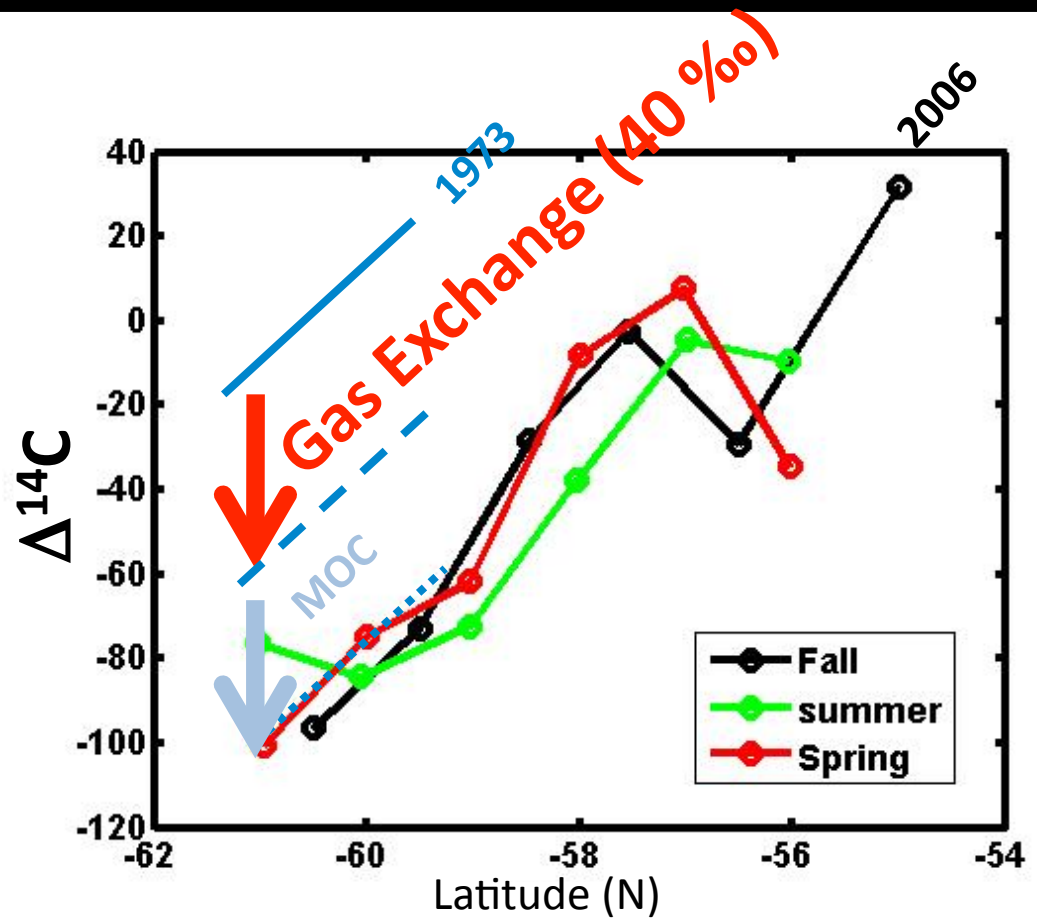
Surface $\Delta^{14}C$ in the Drake Passage



Region	GEOSECS - Present (‰)	Gas Exchange	GEOSECS – WOCE (‰)	Gas Exchange
Drake	70±14	49	34±14	30

- **Gas Exchange only accounts for 75% of the change $\Delta^{14}C$ since 1973**
- **There has been a significant change $\Delta^{14}C$ gradient (45‰ to 85‰)**

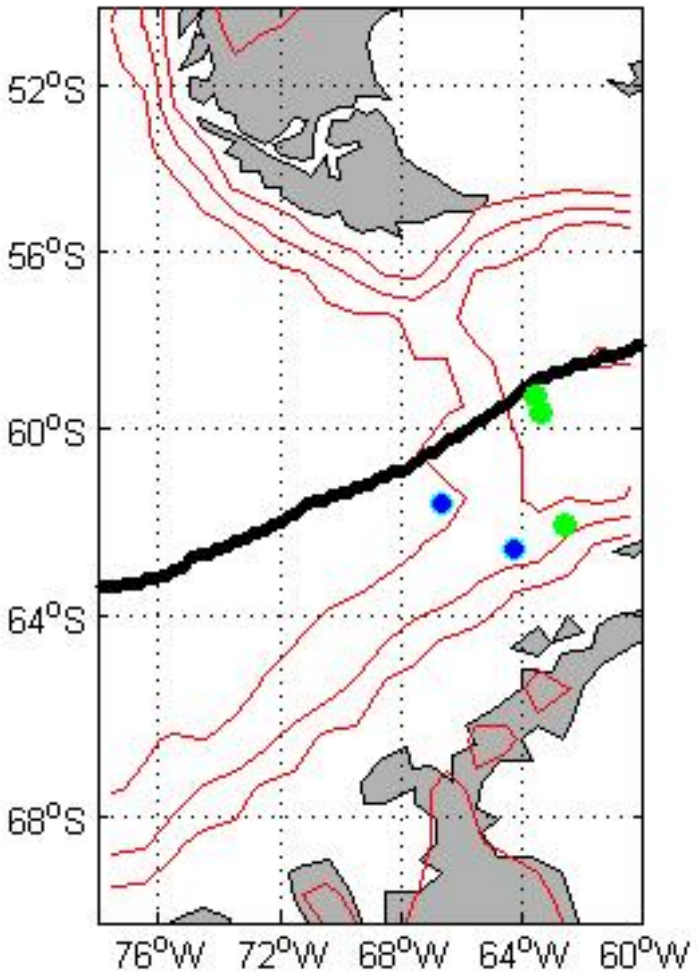
Surface $\Delta^{14}C$ in the Drake Passage



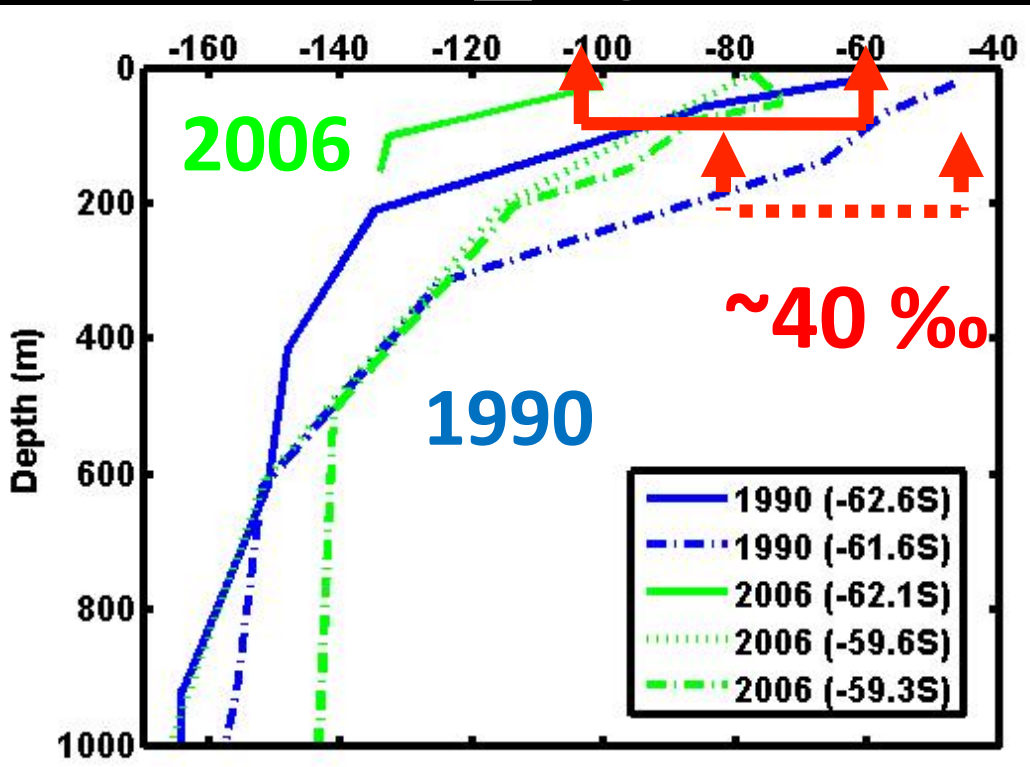
Gas Exchange only accounts for 50% of the change **$\Delta^{14}C$ since 1973**

Change in Surface water $\Delta^{14}C$

1990 - 2006

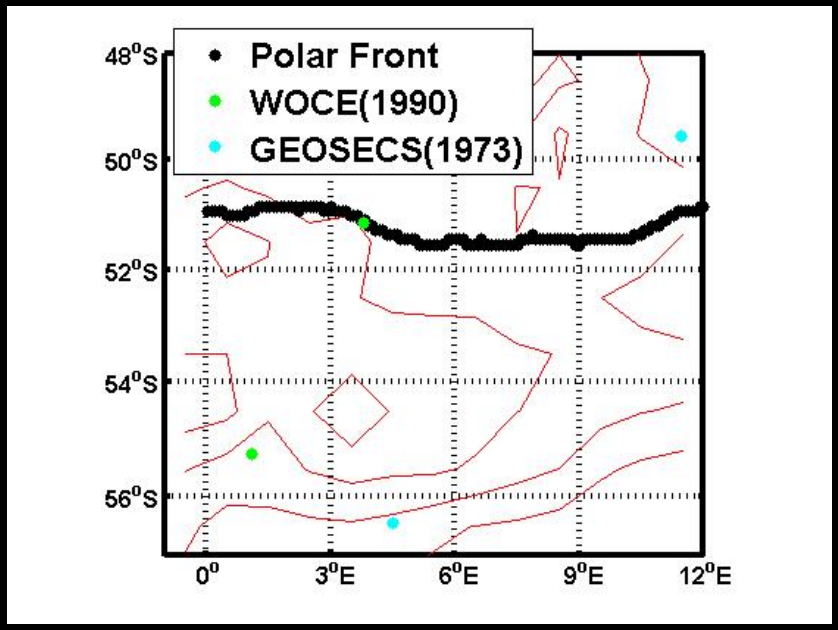


$\Delta^{14}C$

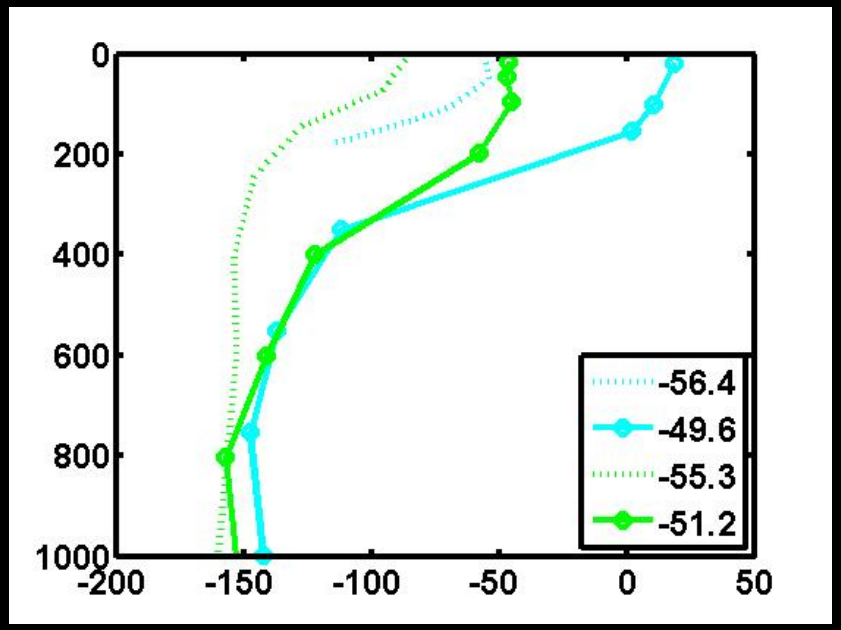


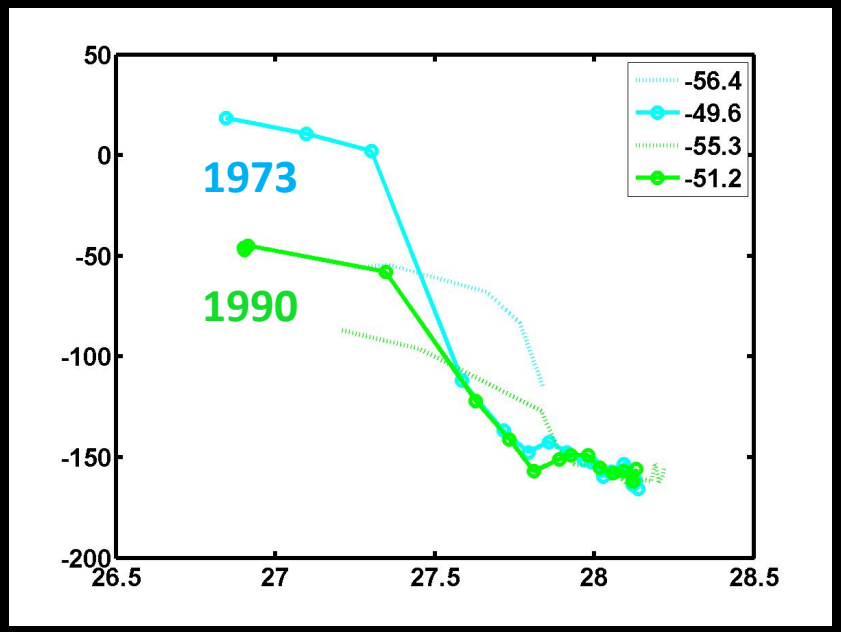
Comparison of surface water $\Delta^{14}C$ 1990 - 2006 suggests change of 40 ‰ and gas exchange accounts for 30‰

Atlantic

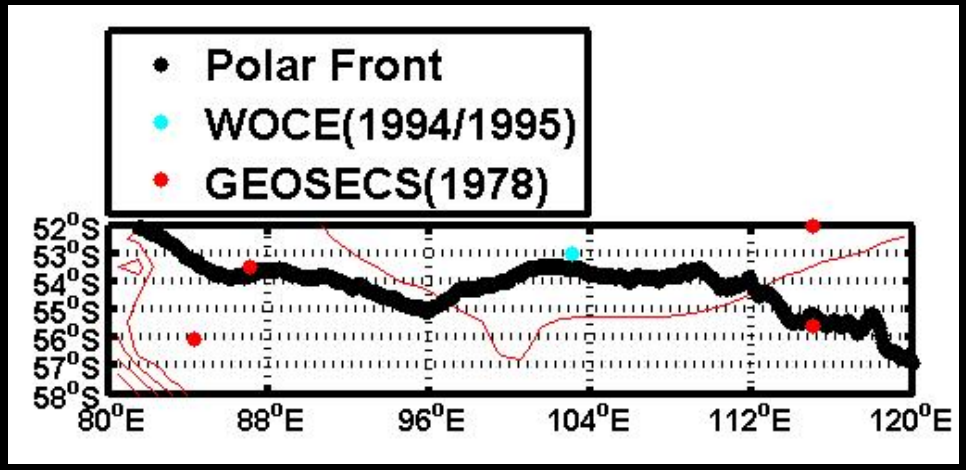


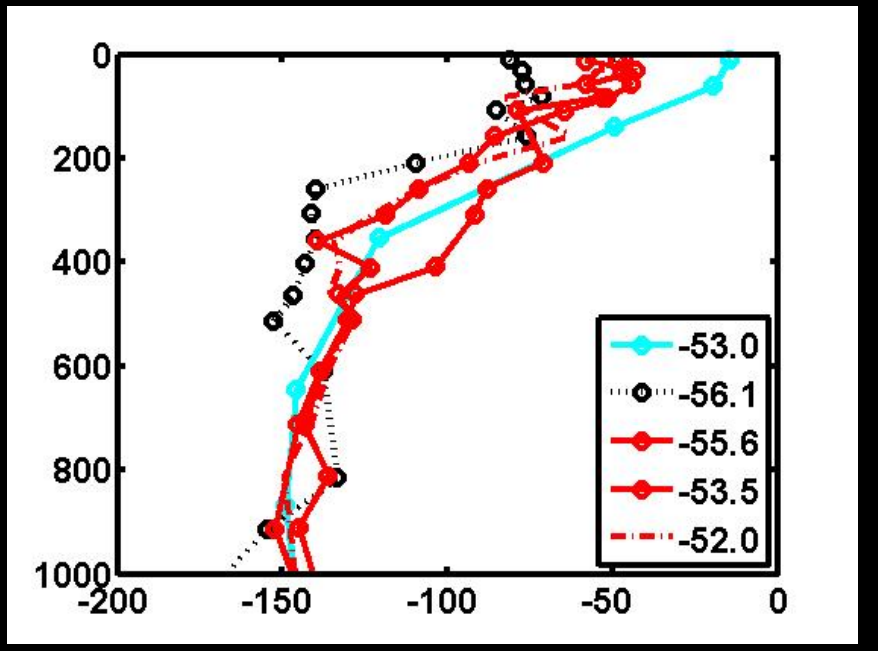
$\Delta^{14}C$ change
1973 – 1990
= -70 ‰
Gas exchange
= -34‰



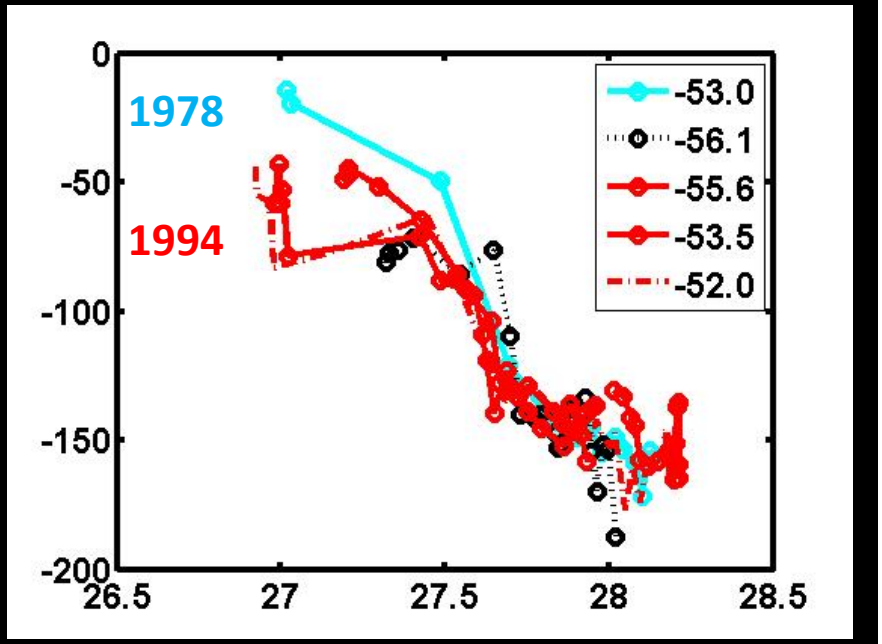


Indian

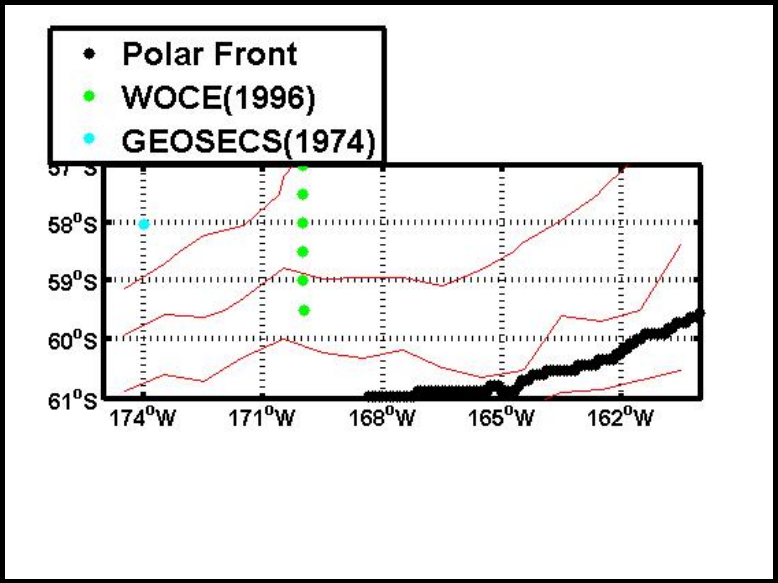


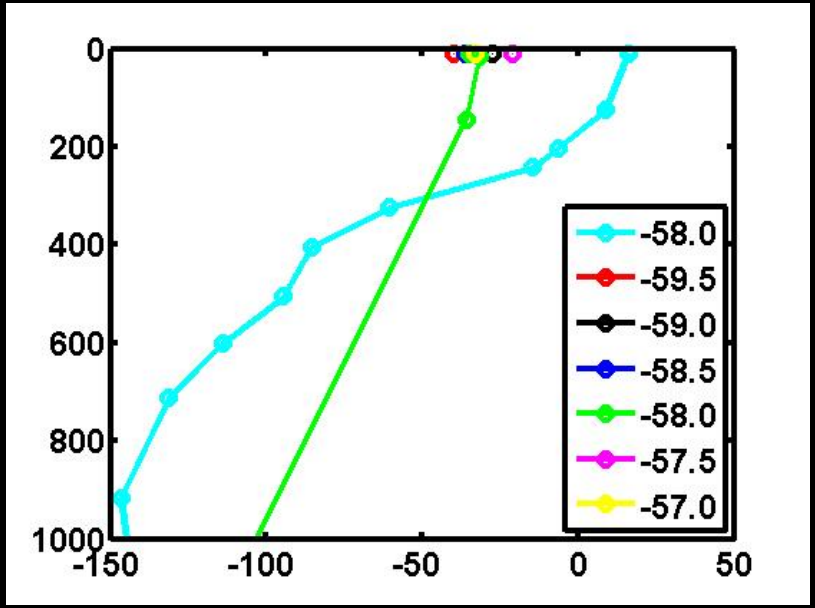


$\Delta^{14}C$ change
1978 – 1995
= -40 ‰
Gas exchange
= -34‰

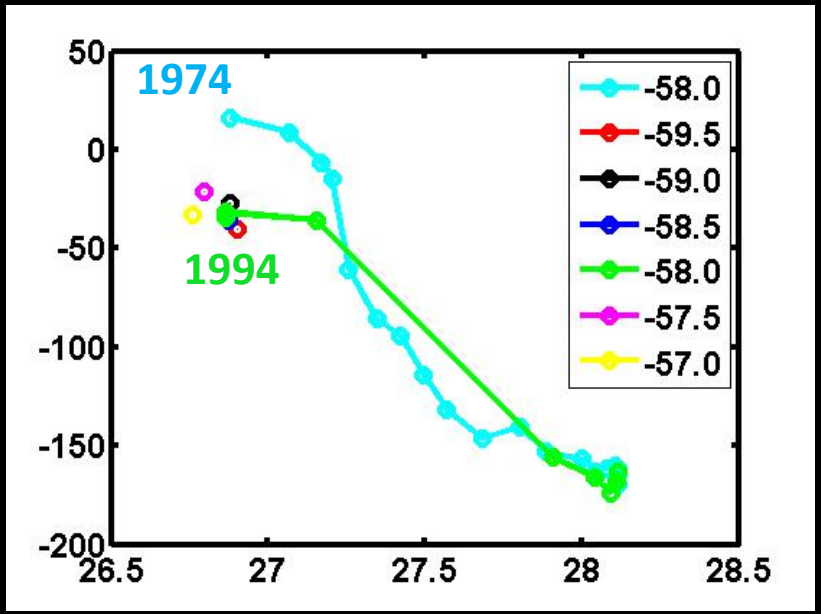


Pacific





$\Delta^{14}C$ change
1974 – 1996
= -46 ‰
Gas exchange
= -37‰



Conclusion

- **Data suggests that the models may actually may be significantly underestimating the decrease in the southern ocean sink.**
- **^{14}C decrease in surface waters suggest that MOC may be the cause of CO_2 sink decrease**

Caveats

- **Better models needed to confirm role of gas exchange with respect to ^{14}C**