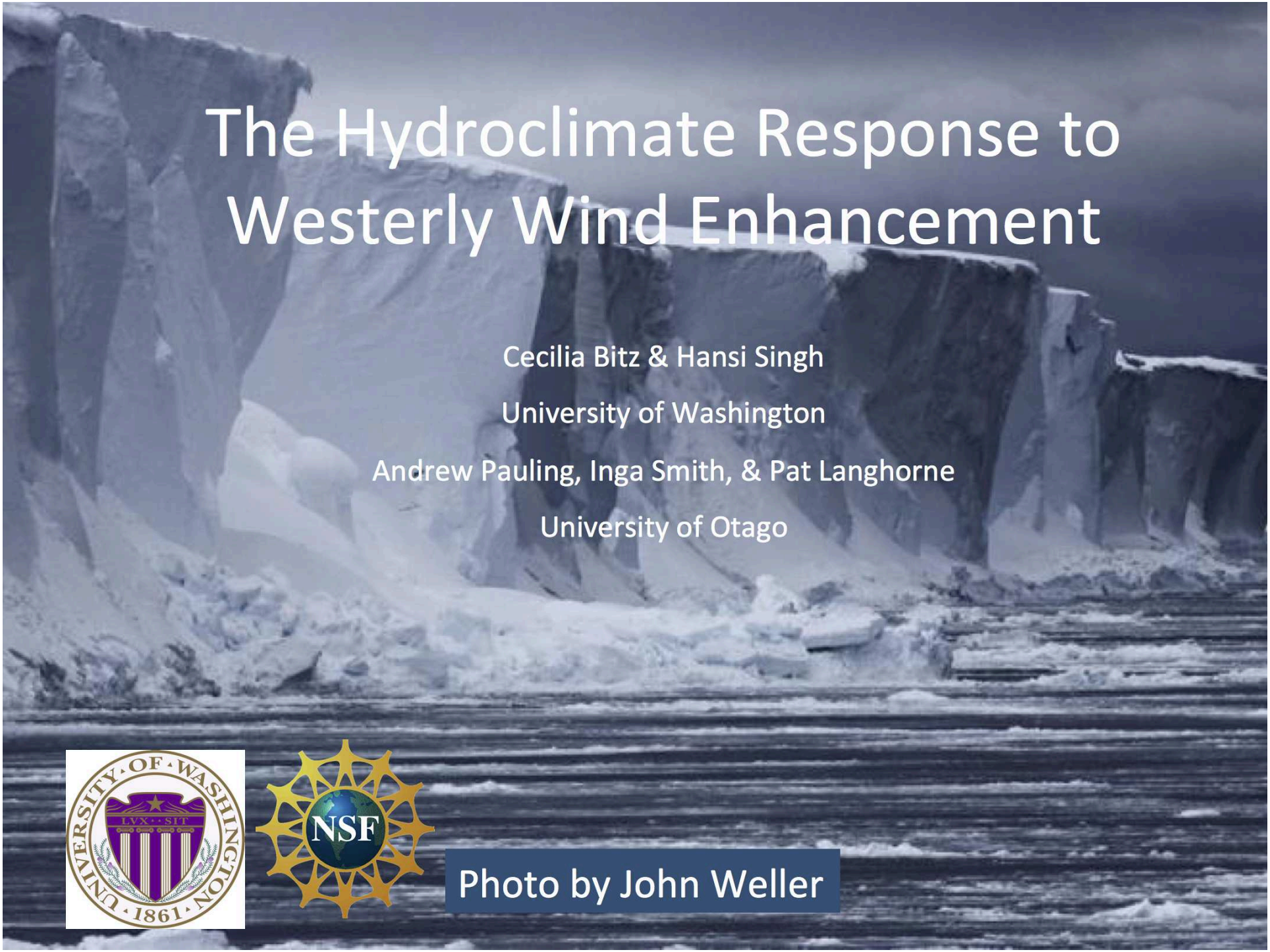


# The Hydroclimate Response to Westerly Wind Enhancement

Cecilia Bitz & Hansi Singh

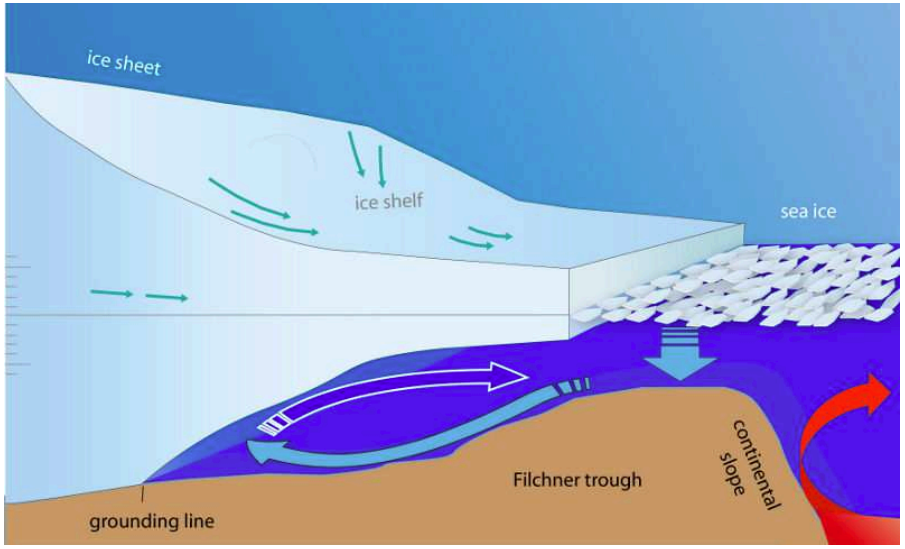
University of Washington

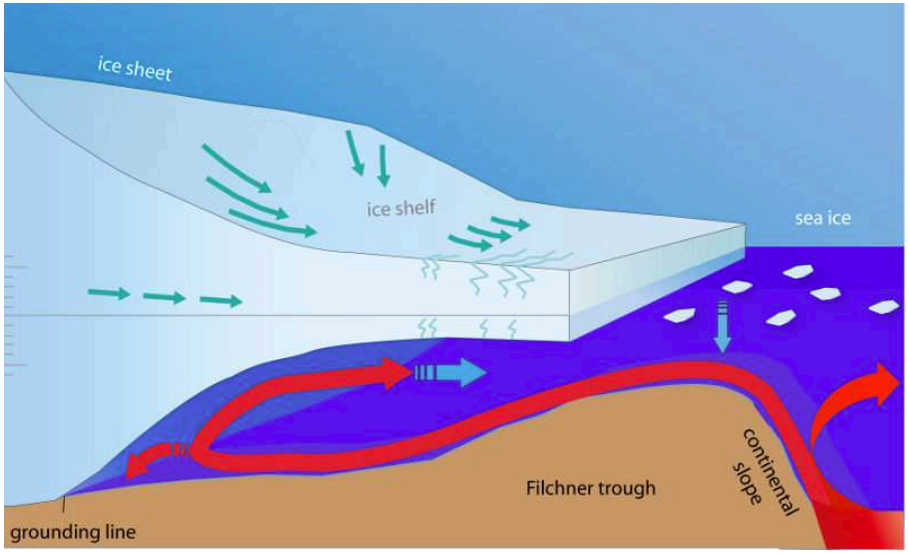
Andrew Pauling, Inga Smith, & Pat Langhorne

University of Otago

Photo by John Weller

# Ice Shelf Cavity Circulation Response to Warm Water Inflow (e.g., from Increased Westerlies)



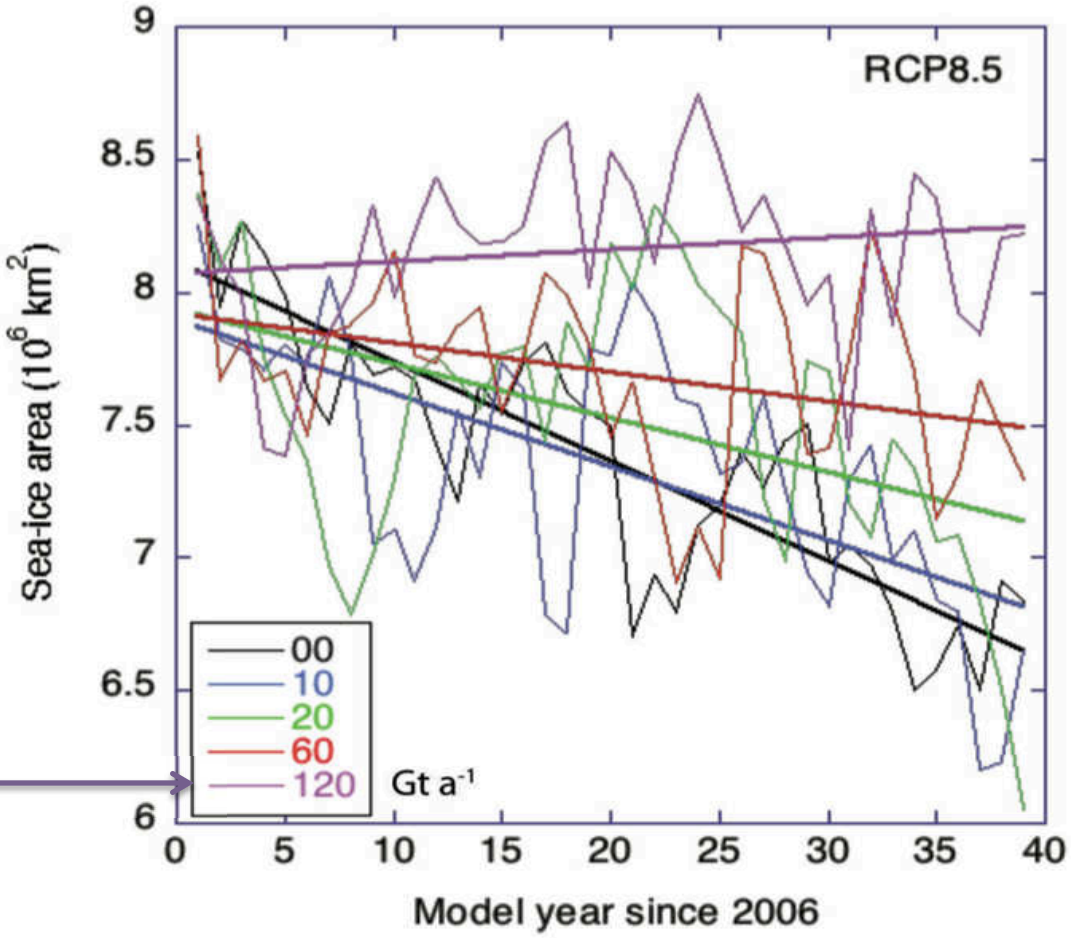




What happens to the Southern Ocean and sea ice?

Cartoons by Dr. Hartmut Hellmer
https://www.awi.de/en/about-us/service/press/archive/climate-scientists-discover-new-weak-point-of-the-antarctic-ice-sheet.html

# Annual Sea Ice Area Forced with RCP8.5 and Freshwater in the EC-EARTH model

Bintanja et al (2014)



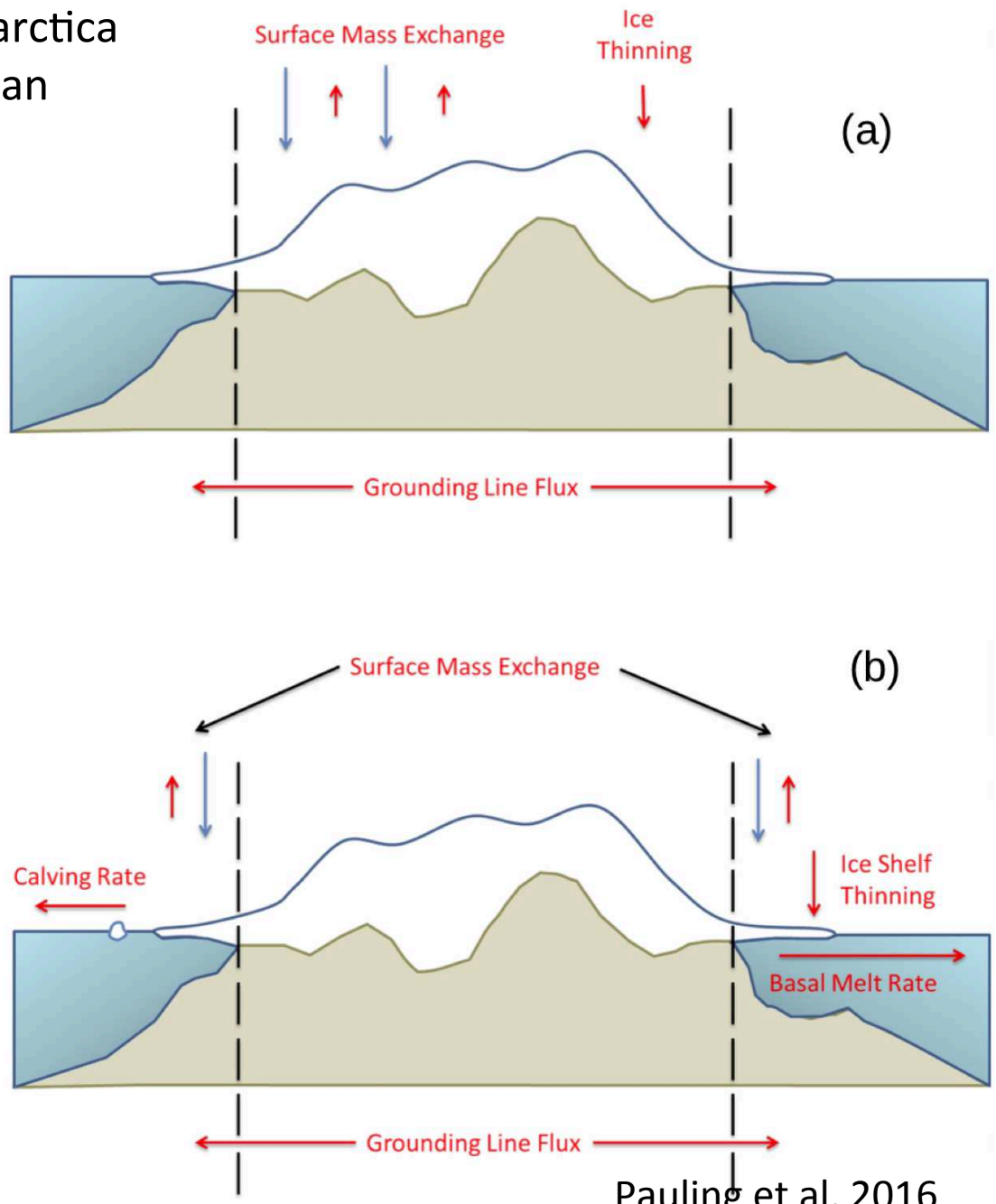

0.004 Sv

Swart & Fyfe (2013) found the “freshwater effect on sea ice trends over the historical period is small and fails to reproduce the observed regional pattern of trends”

How Much Freshwater from Antarctica Is Reaching the Southern Ocean in reality?

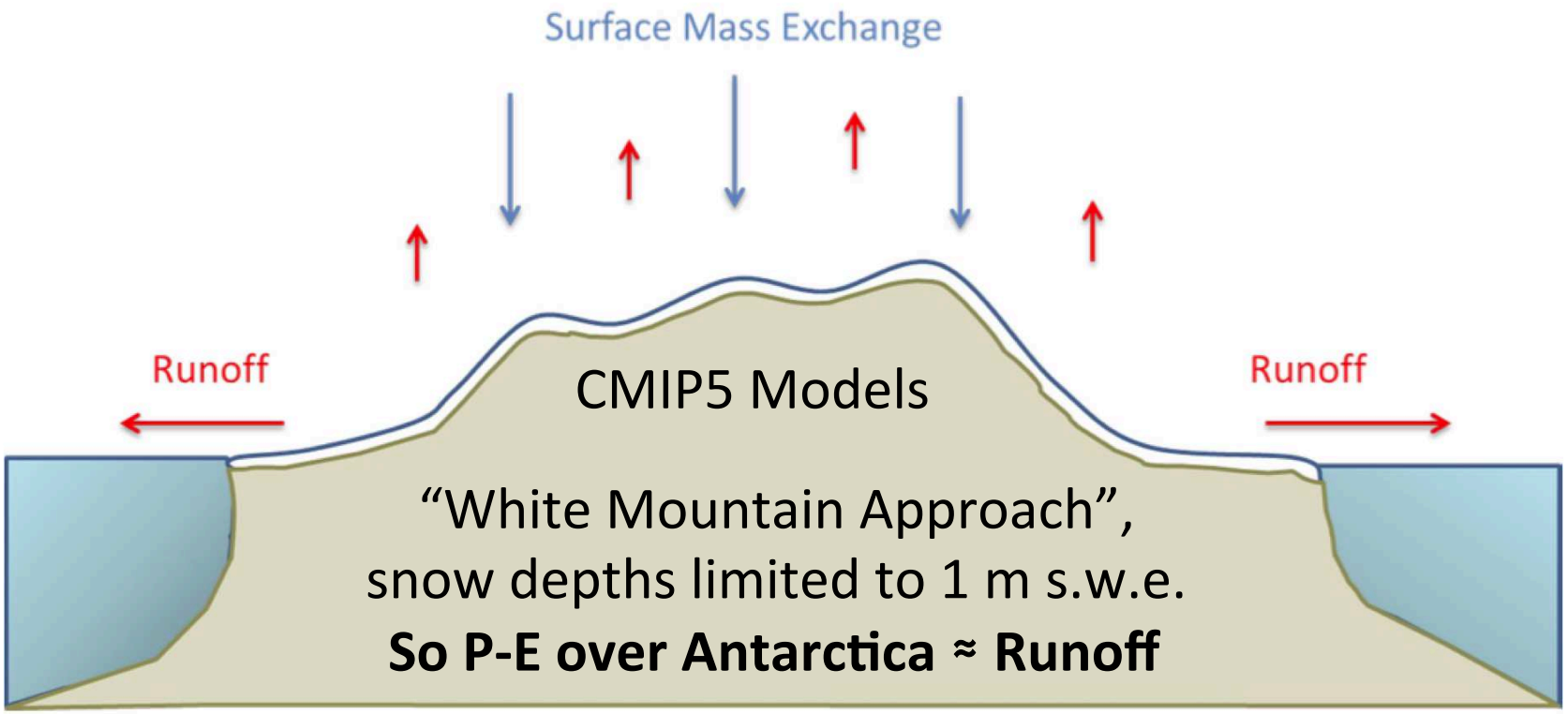
If in balance, the net snowfall accumulation 2,500 Gt/yr (0.08 Sv) must equal iceberg calving & ice shelf basal melt flux

"Independent" estimates of current ice shelf basal melt and iceberg flux is ~2,800 Gt/yr




Pauling et al, 2016

# How Much Freshwater from Antarctica Is Reaching the Southern Ocean in models?

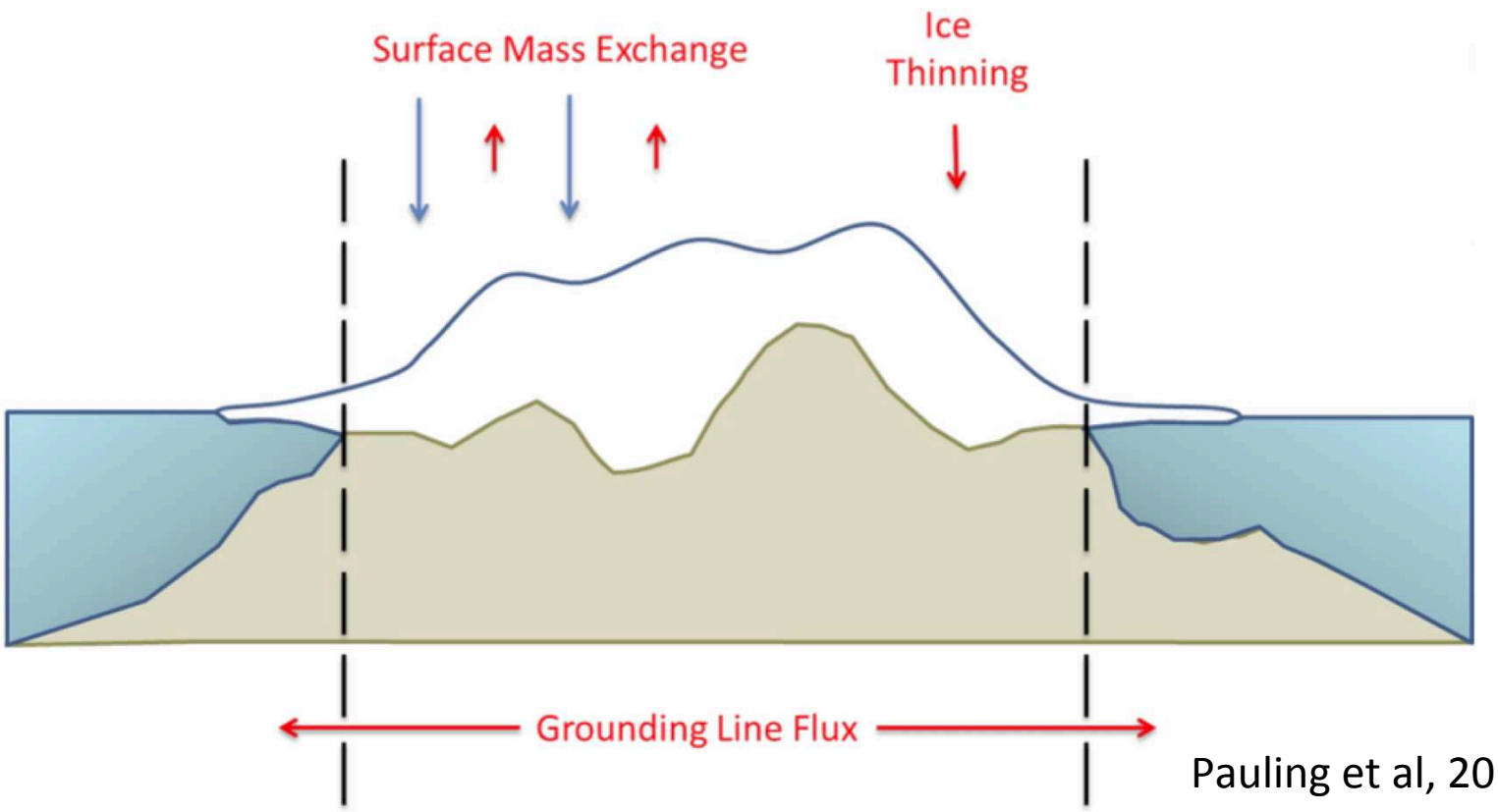



This "Runoff" averages 2,600 Gt/yr (0.08 Sv)
mimics iceberg calving & basal melt flux

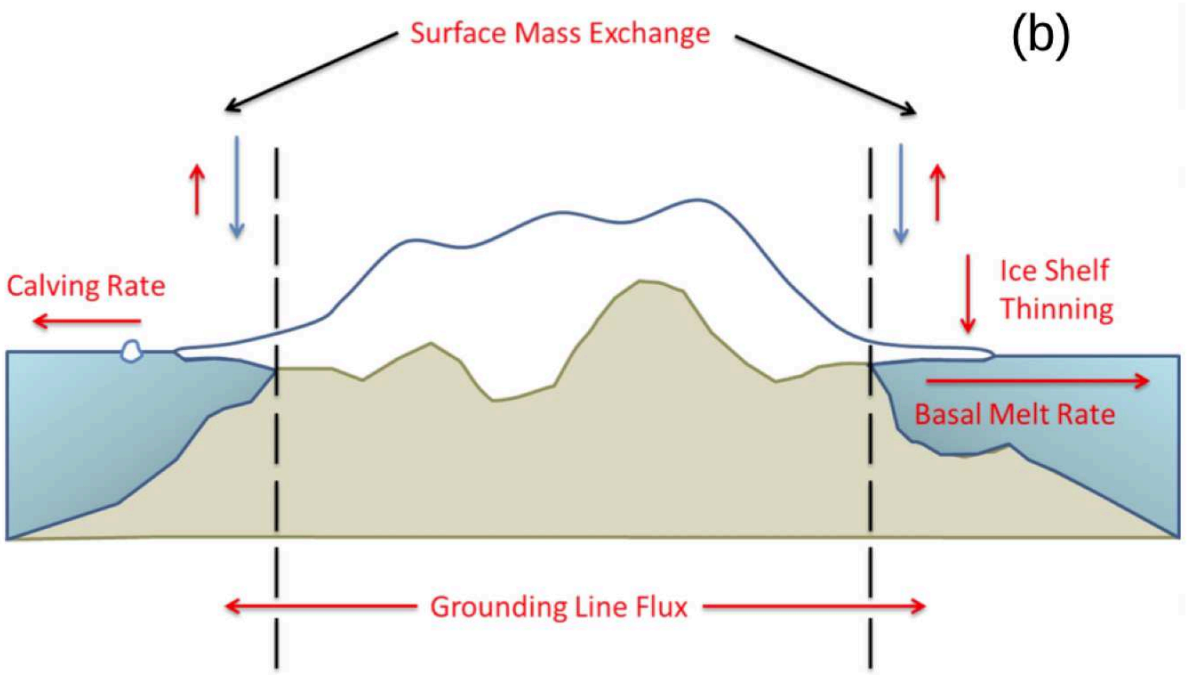
Pauling et al, 2016

# How has the freshwater source **changed**?

Recent gravimetric estimates of the GROUNDED ice mass **imbalance** is ~30-250 Gt/yr … This affects sea level rise




Pauling et al, 2016



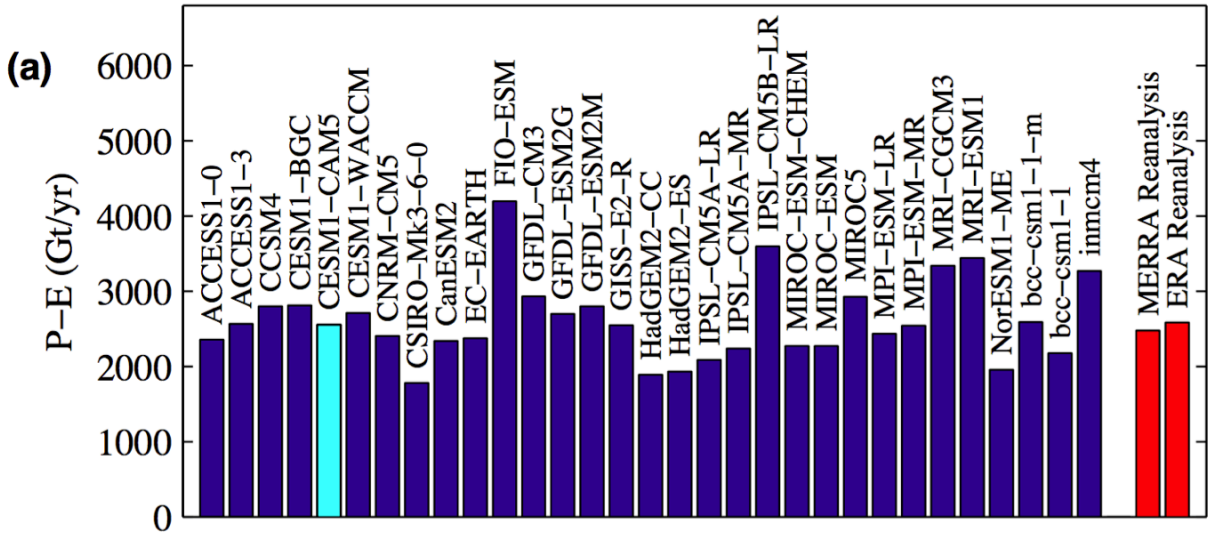

The ice shelf mass **imbalance** is 90-290 Gt/yr

The combination of grounded and shelf ice mass **imbalance** is 120-550 Gt/yr

(perhaps equals the increase since pre industrial?)

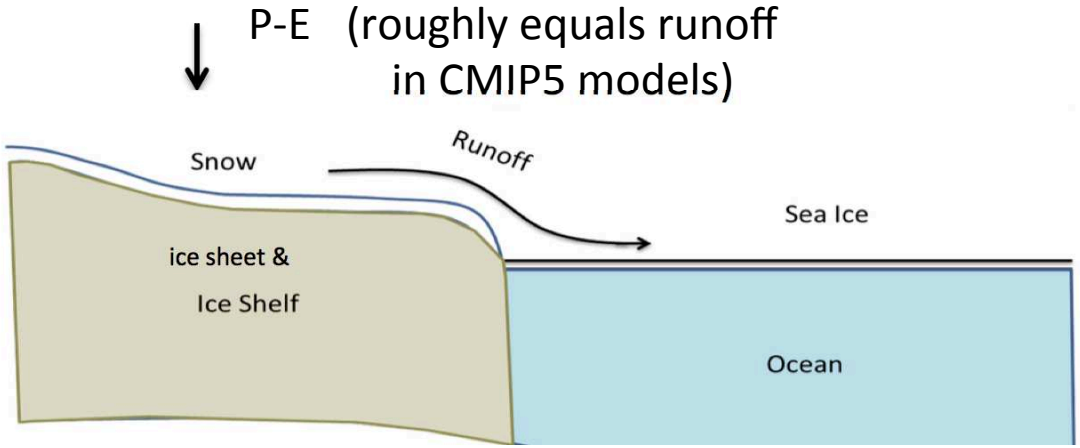
Pauling et al, 2016

# 1994-2013 P-E on Antarctica in CMIP5 Historical Runs and Reanalyses




~2,600 Gt/yr
Annual Antarctic mean

(CMIP5 up ~600 Gt/yr since pre-industrial)




- In models P-E ≈ "runoff"
- change since pre-industrial miraculously (?) resembles the current grounded ice and shelf ice imbalance

Pauling et al, 2016

# Numbers Summary

Real world sources of freshwater to Antarctica & Southern Ocean

- Antarctica surface mass budget 2,500 Gt/yr
- ice shelf basal melt & iceberg flux 2,800 Gt/yr
- Antarctic land/shelf ice mass imbalance 120-550 Gt/yr

CMIP5 model sources of freshwater to Southern Ocean

- P-E (and hence "runoff") from Antarctica 2,600 Gt/yr
- P-E (and hence "runoff") from Antarctica increased by 600 Gt/yr since pre industrial

Bottomline: CMIP5 models look good, for now

# 1994-2013 P-E Directly into Southern Ocean* in CESM1-CAM5 and Merra Reanalyses

~8 X bigger than amount that falls on land/shelf ice

~20,000 Gt/yr
Annual mean
*oceans south of outer flank of ACC

# Increase in P-E at 1994-2013 since Pre Industrial in CESM1-CAM5 Historical Runs over Southern Ocean & Antarctica

~860 Gt/yr

Annual mean

*oceans south of outer flank of ACC

Much more than Antarctic land/shelf ice mass imbalance

120-550 Gt/yr

Increase in P-E at in CCSM3.5 due to
Ozone Depletion Only over
Southern Ocean* & Antarctica

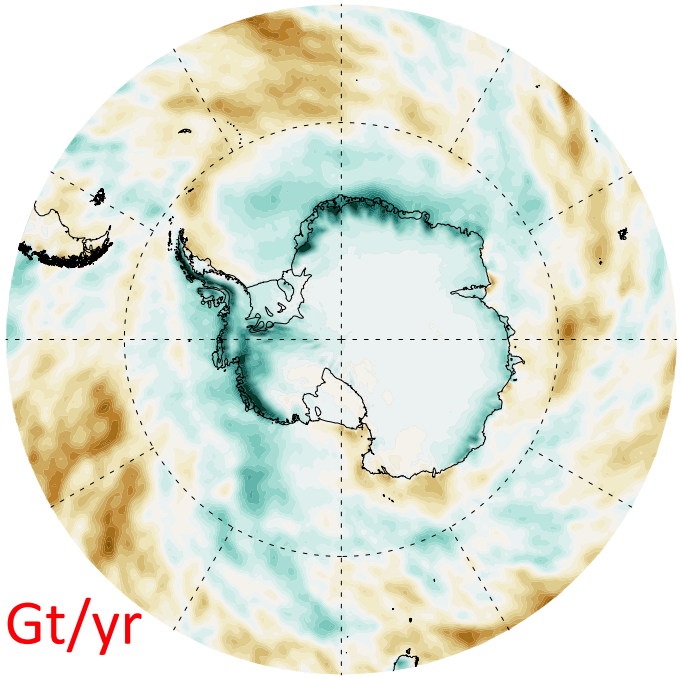
~300 Gt/yr
Annual mean
*oceans south of outer flank of ACC

~ 1/3 of the increase in P-E in same region in 1994-2013 since pre industrial

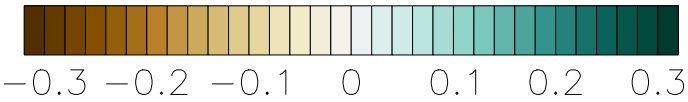
Above middle of the range of Antarctic land/shelf ice mass imbalance estimates

# Annual Mean P-E Response

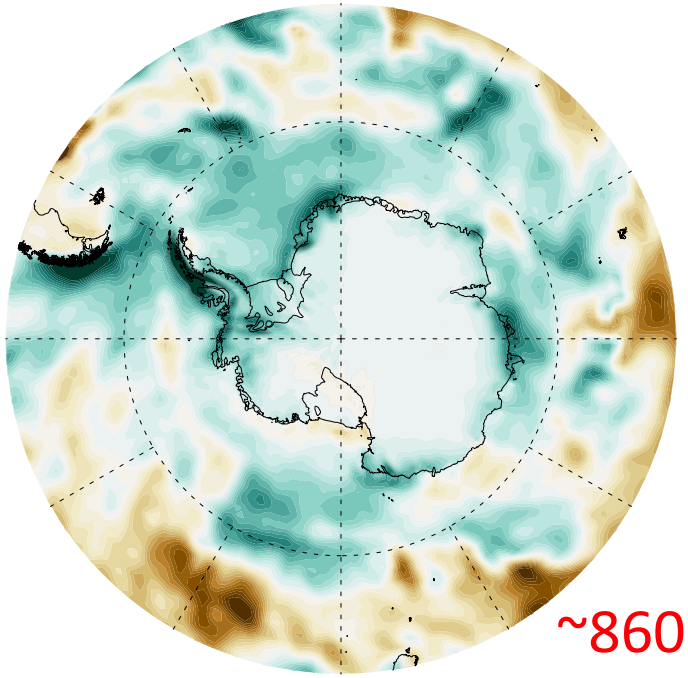
in CCSM3.5 due to
Ozone Depletion Only



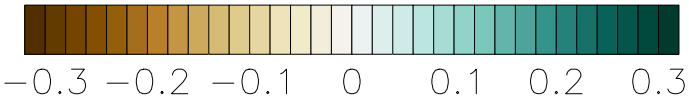
~300 Gt/yr




in CESM1-CAM5 1994-2013
relative to pre industrial



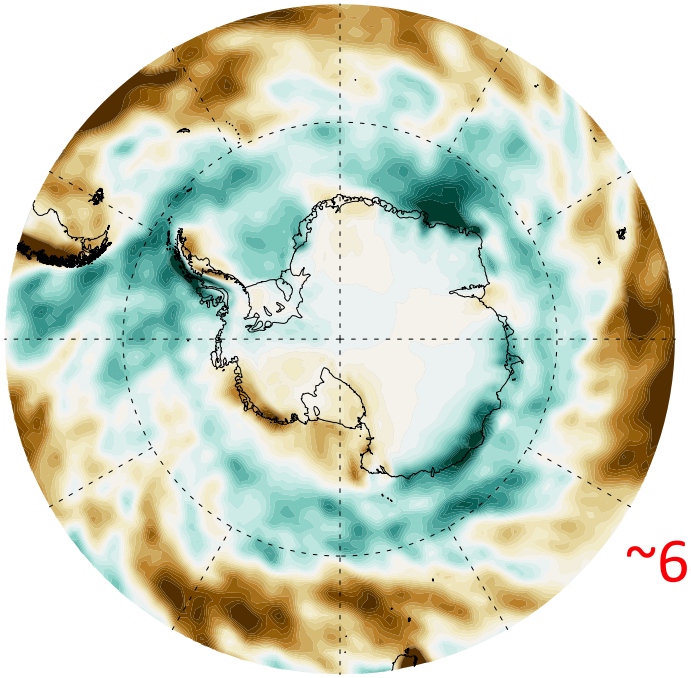
~860 Gt/yr



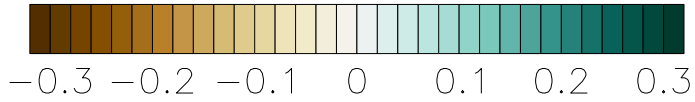

Annual P-E Response in mm/day

# Annual Mean P-E Response to SAM* in CESM1-CAM5

*20% highest minus 20% lowest SAM summers

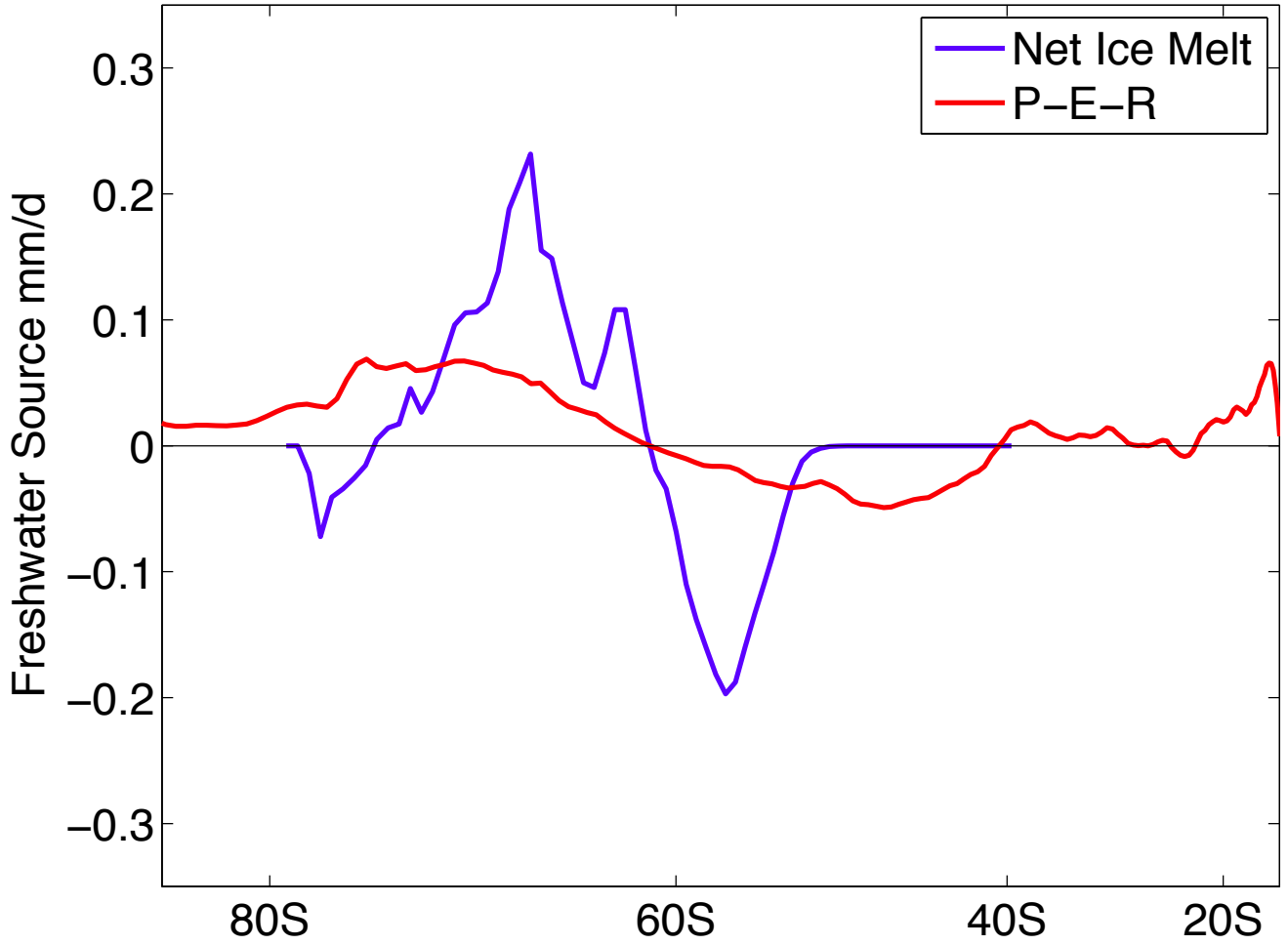


~640 Gt/yr




Annual P-E Response in mm/day

# Annual Zonal Mean Response of Sea Ice and P-E-R from Ozone Depletion Only

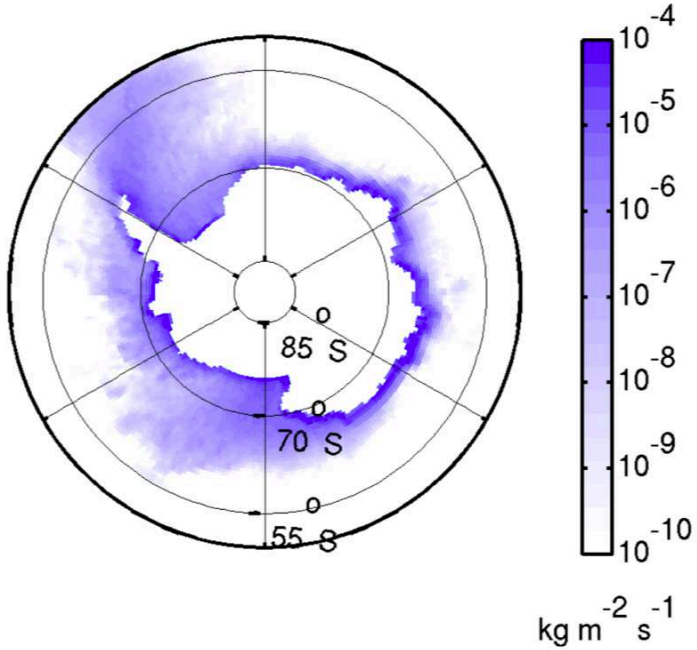


# Freshwater Enhancement Experiments

CESM1-CAM5 Historical & RCP8.5 Forcing for 1980-2013 branched from “Large Ensemble”

In Set 1: We added freshwater at the surface in total amounts of 1000, 2000 (3 ensemble members), and 3000 Gt/yr with this distribution pattern:

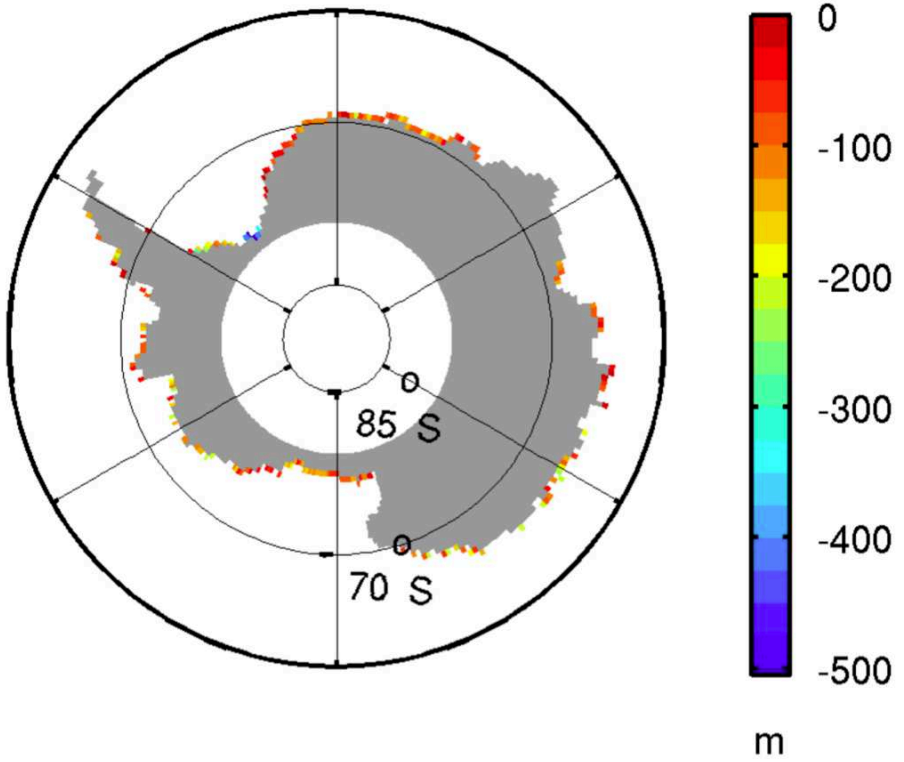
Mimics iceberg melt input



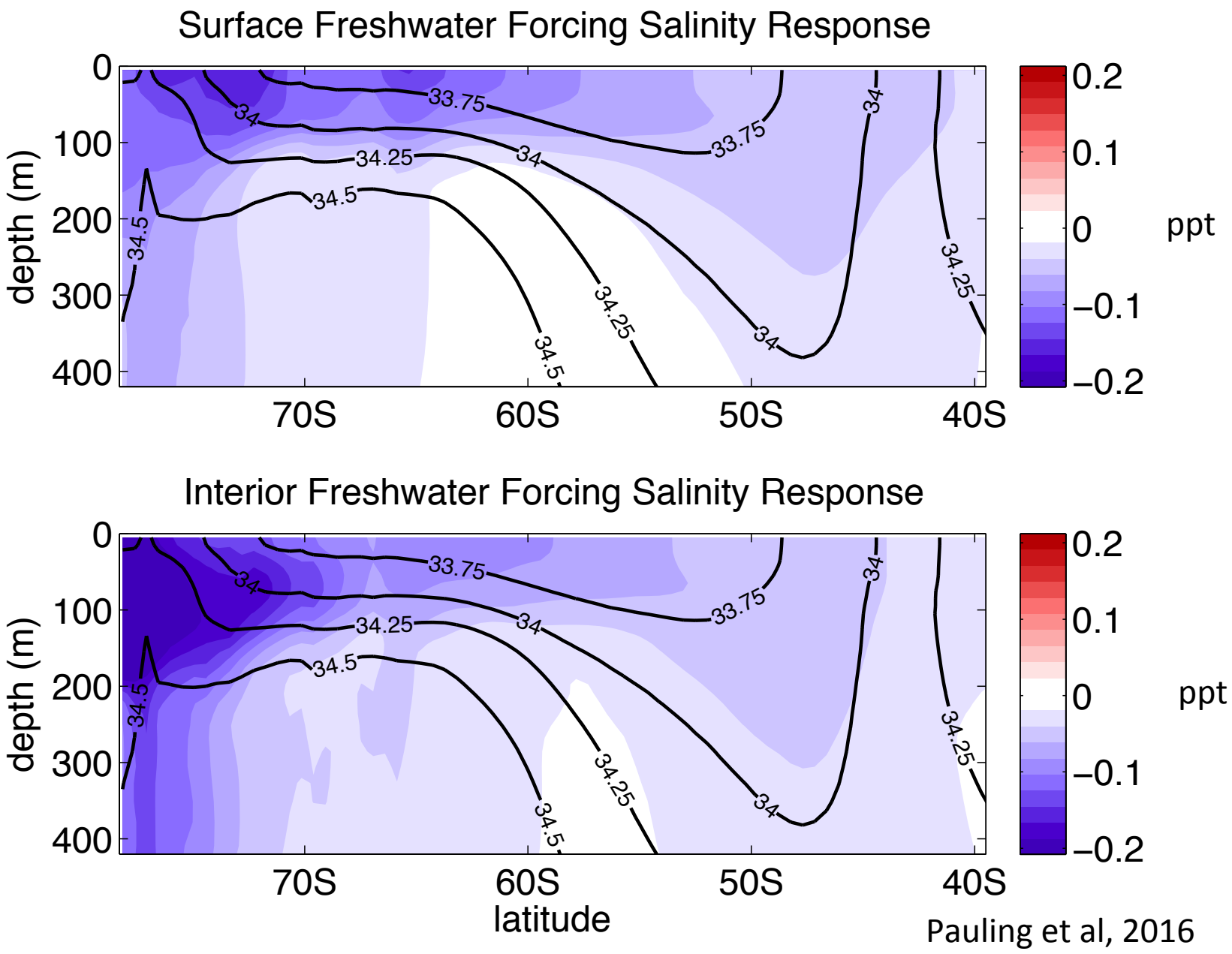
# Freshwater Enhancement Experiments

In Set 2: We added freshwater at the depth of ice shelf cavities at their calving front surface at 167 and 2000 Gt/ yr (2 ensemble members)

Mimics ice shelf basal melt input

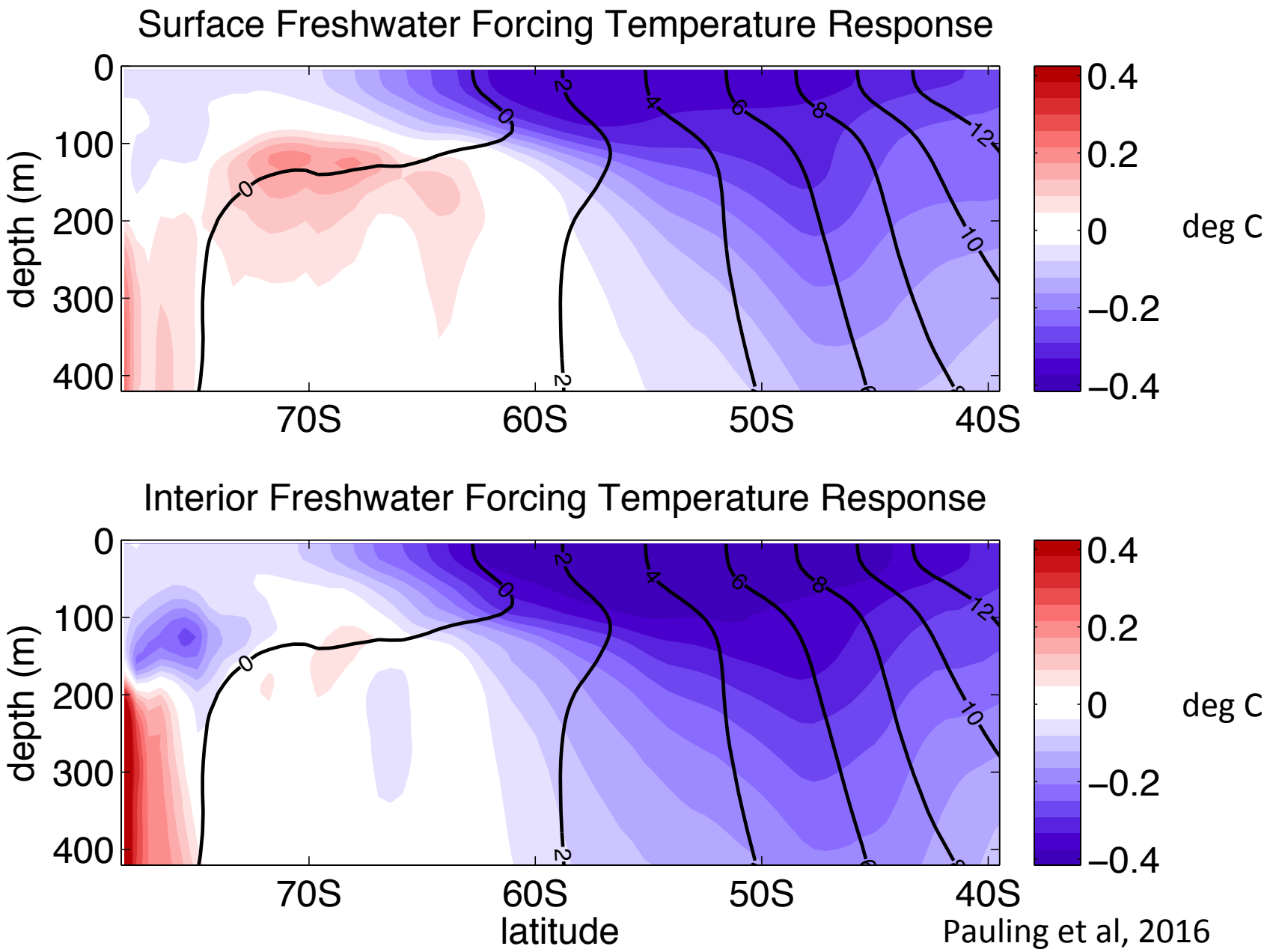


Year 1994-2013 mean from 2000 Gt/yr experiments




Pauling et al, 2016

Year 1994-2013 mean from 2000 Gt/yr experiments

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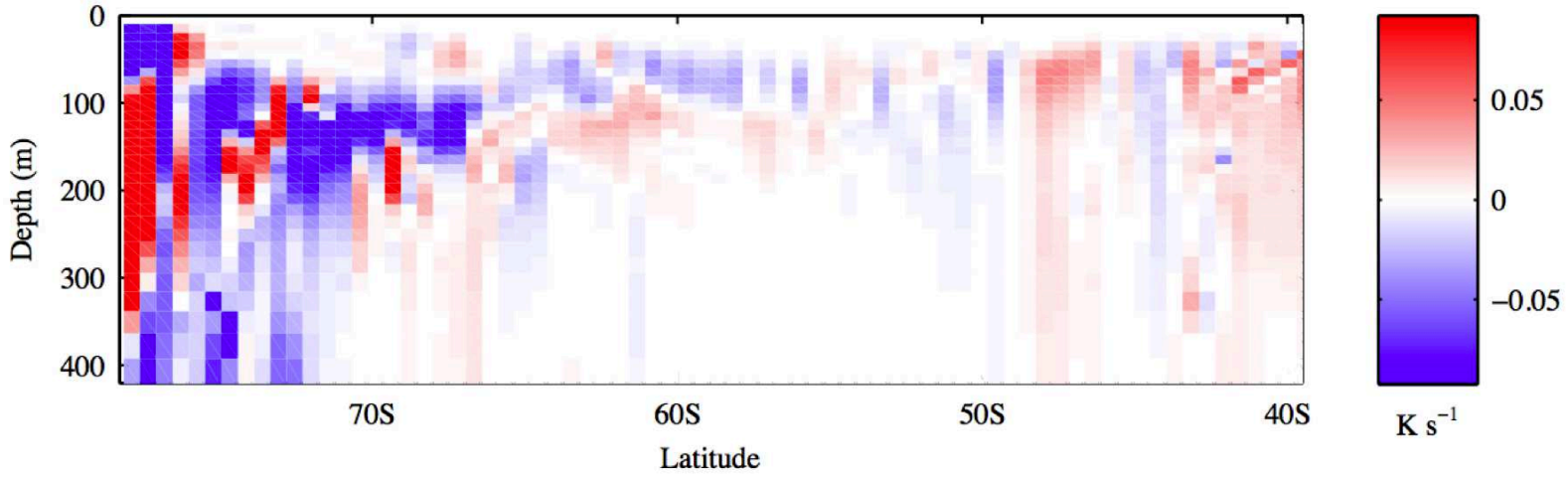
# Advective Temperature Tendency

Year 1994-2013 mean from 2000 Gt/yr interior experiments



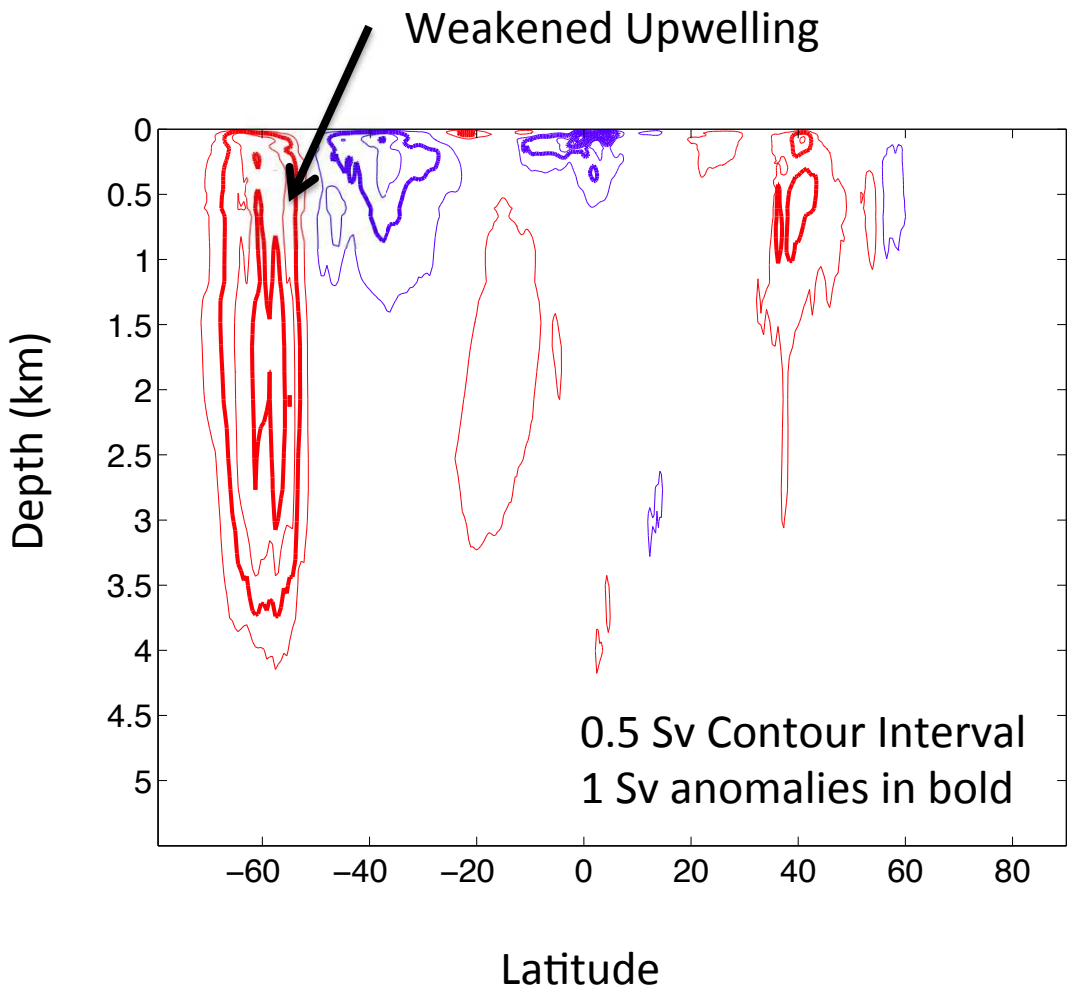

$$\frac{\partial \Delta T}{\partial t} \approx -\Delta w_{\text{res}} \frac{\partial \overline{T}}{\partial z}.$$

Explains cooling/warming south of 65 S

Enhanced northward heat transport and feedbacks cause cooling 40-60S

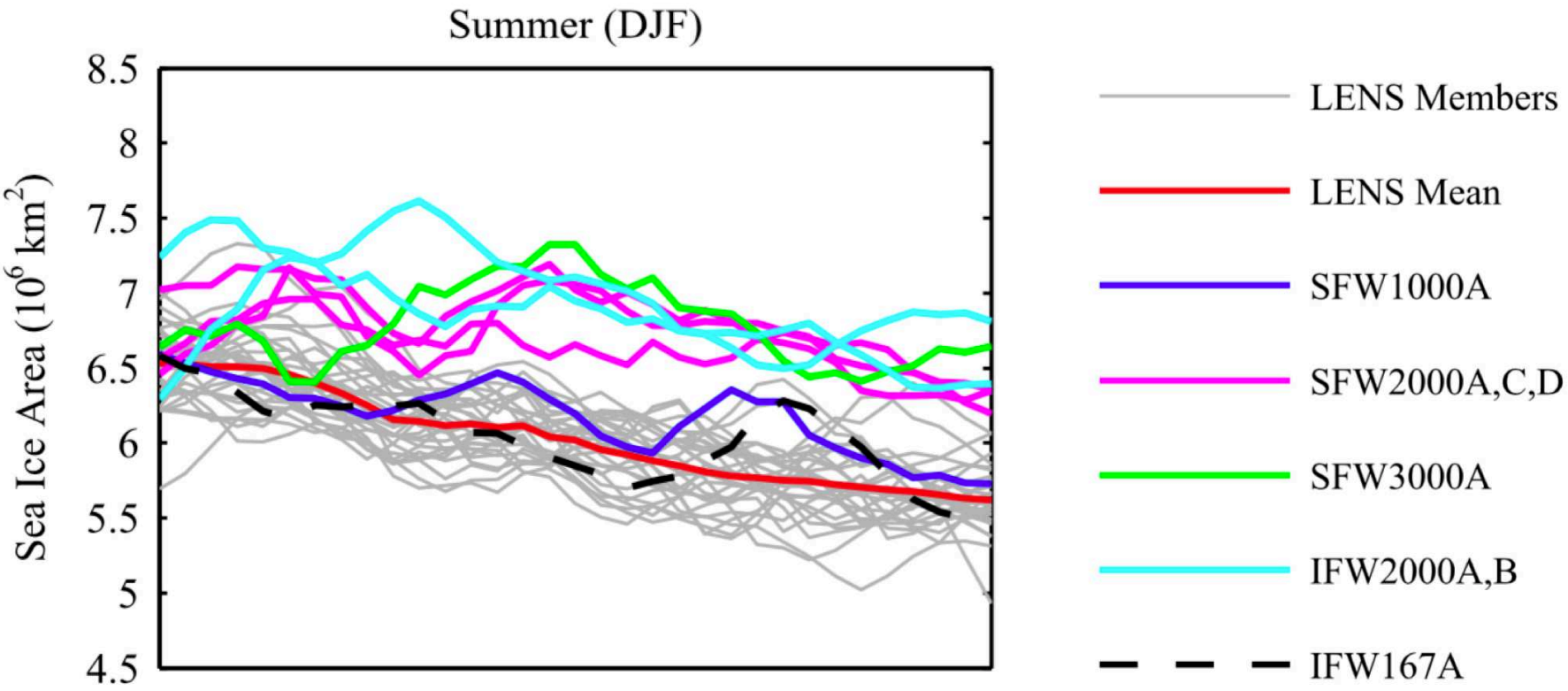
Pauling et al, 2016

# Stabilizing Effect of the 3000Gt Surface Freshening on Overturning




Weakened upwelling where ocean normally brings up warm water

# Sea Ice Response

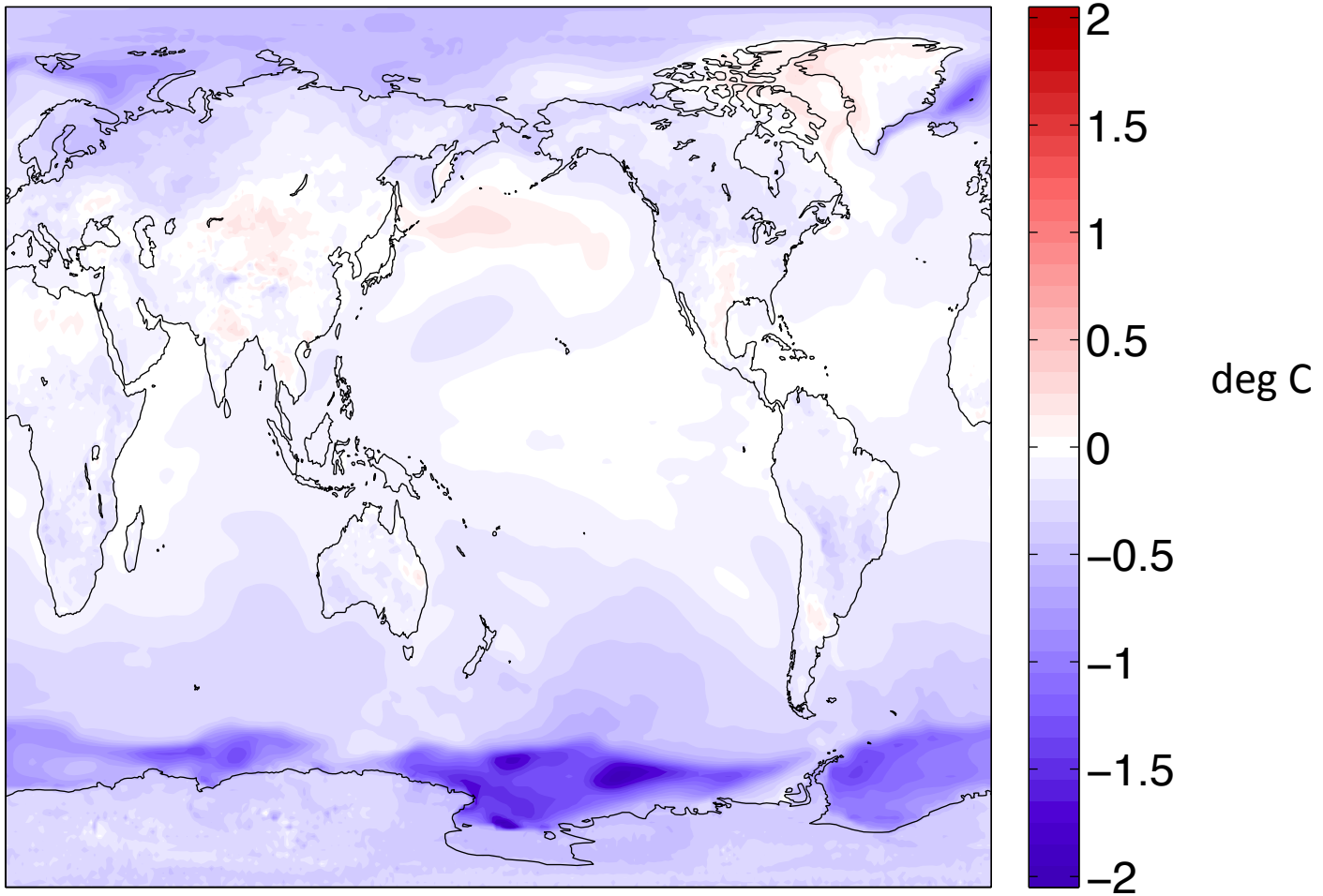



At most 1 million square km greater, but still negative trend

Pauling et al, 2016

# Surface Temperature Response

Year 1994-2013 mean of 2000 Gt/yr surface experiments



# Summary

Freshwater due to ozone depletion and all other recent natural and anthropogenic sources has a small but straightforward influence on the Southern Ocean

One study mysteriously found a very big response to tiny amounts of freshwater

Similar climate impact of iceberg flux vs ice shelf basal melt

# Annual Zonal Mean of Sea Ice and P-E-R from 1994-2013