Our Climate without Antarctica

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

What happens to the Southern Ocean and sea ice?

Cartoons from http://takvera.blogspot.co.uk/2012/05/waking-giant-global-warming-in-weddell.html
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?

“White Mountain Approach”, snow depths limited to 1 m s.w.e.
So P-E over Antarctica ≈ Runoff

This “Runoff” should mimic key Antarctica ice sinks, which are ice shelf basal melt & iceberg flux 2,800 Gt/yr

Pauling et al, submitted
How has the freshwater source changed?

Recent gravimetric estimate of the GROUNDED ice mass imbalance is ~100 Gt/yr ... This affects sea level rise

Pauling et al, submitted
Ice shelves do NOT directly affect gravimetric estimates.

Ice shelf basal melt and iceberg flux are source of freshwater of ~ 2,800 Gt/yr

The ice shelf mass imbalance is 310-750 Gt/yr (an additional source since pre industrial?)

CMIP5 models always have P-E ≈ “runoff”, which miraculously (?) resembles the total from shelf basal melt and icebergs and the change in P-E since pre industrial resembles the imbalance

Pauling et al, submitted
1994-2013 Mean P-E on Antarctica in CMIP5 and Reanalyses

P-E (roughly equals runoff in CMIP5 models)

~2,600 Gt/yr
(up ~600 Gt/yr since pre-industrial)

Pauling et al, submitted
Numbers Summary

Real world sources of freshwater to Southern Ocean
- P-E over S. Ocn  25,000 Gt/yr
- ice shelf basal melt & iceberg flux  2,800 Gt/yr
- Shelf ice mass imbalance  310-750 Gt/yr

CMIP5 model sources of freshwater to Southern Ocean
- P-E over S. Ocn  25,000 Gt/yr
- P-E (and hence “runoff”) from Antarctica  2,600 Gt/yr
- P-E (and hence “runoff”) from Antarctica is up 600 Gt/yr

Bottomline: CMIP5 models look good, for now
Our 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 900, 1800 (3 ensemble members), and 2700 Gt/yr with this distribution pattern:

Mimics iceberg melt input
Our Freshwater Enhancement Experiments

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

Mimics ice shelf basal melt input
Year 1994-2013 mean from 1800 and 2000 Gt/yr experiments

Pauling et al, submitted
Year 1994-2013 mean from 1800 and 2000 Gt/yr experiments

Pauling et al, submitted Year 1994-2013 mean from 1800 and 2000 Gt/yr experiments
Advective Temperature Tendency

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

\[ \frac{\partial \Delta T}{\partial t} \approx -\Delta w_{res} \frac{\partial \bar{T}}{\partial z}. \]

Explains cooling/warming south of 65 S
Enhanced northward heat transport and feedbacks cause cooling 40-60S

Pauling et al, submitted
Sea Ice Response

At most 1 million square km greater, but no significant trend!

Pauling et al, submitted
Surface Temperature Response

Year 1994-2013 mean  1800 Gt/yr surface experiments
Summary – part 1

Recent published studies have added a extremely small freshwater flux, yet mysteriously one found a big response.

We had to nearly double the Antarctic freshwater source (i.e., ~5 mm SLR per year) to cause a significant response. Our experiments may be relevant for 21st century, if dynamical loss accelerates.

Similar climate impact of iceberg flux vs ice shelf basal melt.
Extreme change: Abruptly Flatten Antarctica (FA)

Topographic change only, keep it white, no compensating freshwater flux

CCSM4 1.9x2.5 atm/Ind, 1° ocn/Ind 230 yr long also run with SOM at same resolution 60 yr long

“response” in final 30 yrs compared to control
Response to Flattening Antarctica (with OGCM)

Increased OLR over Antarctica

Singh et al, in prep
Zonal Wind Response

Reduced vertical wind shear of the zonal wind

Singh et al, in prep
Baroclinic Instability Criterion Response

Two-layer model

\[ B \equiv \frac{2\lambda^2 U_T}{\beta} > 1 \]

- \( U_T \) = vertical wind shear,
- \( \lambda \) = characteristic eddy wavelength
- \( \beta = \frac{\partial f}{\partial y} \)
- \( \lambda = \frac{f_0^2}{(S \Delta \sigma)^2} \)

Walsh et al (2000) revised B to sigma coordinates

Singh et al, in prep
Northward Energy Transport Response

Mostly dry static energy

Singh et al, in prep
Precipitation Response

with OGCM

with SOM

Singh et al, in prep
with OGCM

Singh et al, in prep
with OGCM

Singh et al, in prep
Summary

Removing topography of Antarctica (without adding freshwater) causes global cooling and increased OLR.

Atmospheric eddy kinetic energy rises in the troposphere in high southern latitudes, with southward anomalous heat transport.

ITCZ and Hadley circulation shift towards the Northern Hemisphere, with southward anomalous cross-equatorial heat transport.

AMOC weakens, also with southward anomalous cross-equatorial heat transport.
Summary

Freshwater input from Antarctica and loss of topography of Antarctica both cause global cooling.