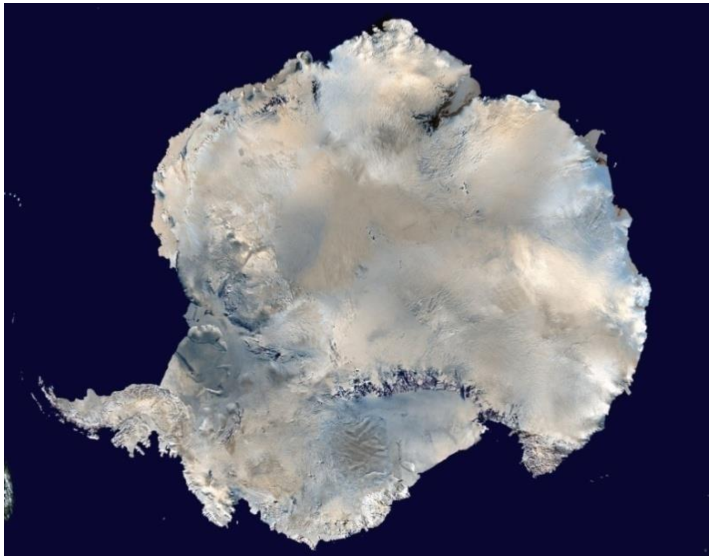
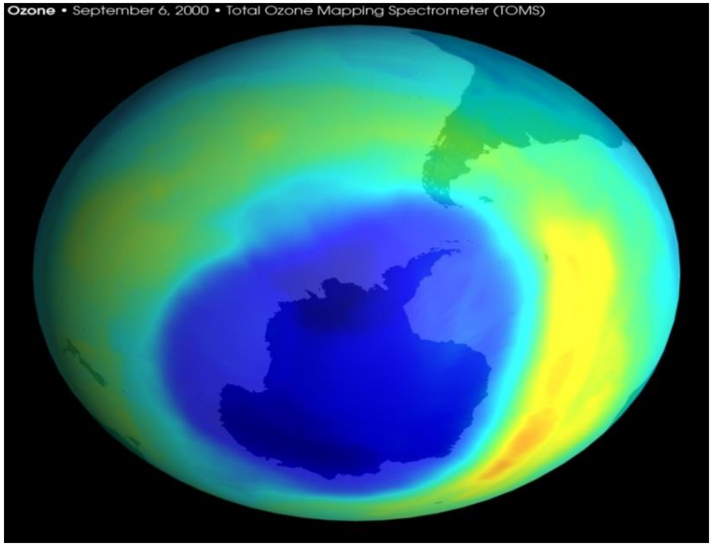
Large radiative forcing due ozone depletion offset by albedo over Antarctica

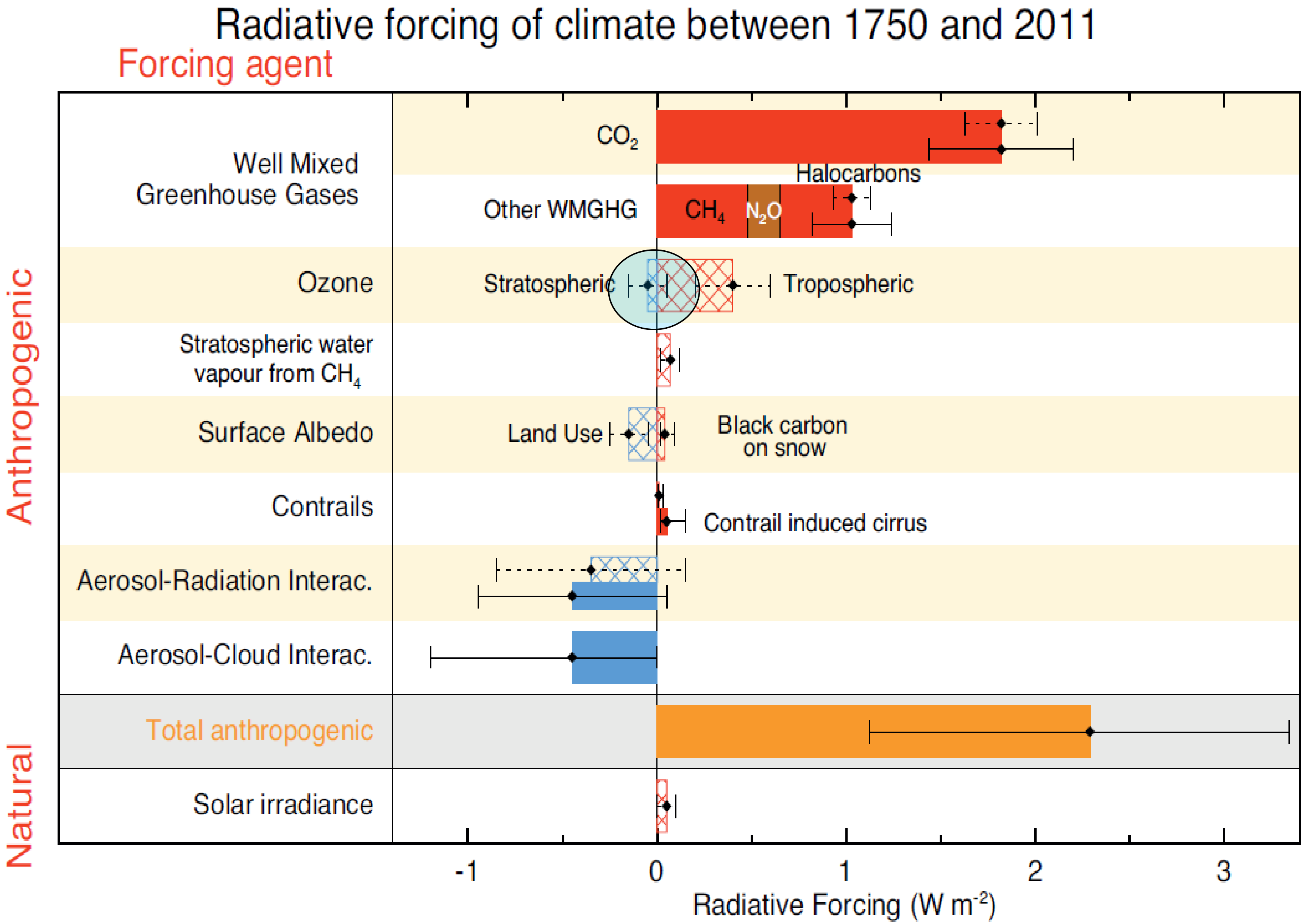
G.Chiodo[1], L.Polvani[12] and M.Previdi[2]

1.Applied Physics and Applied Mathematics, Columbia University, NY

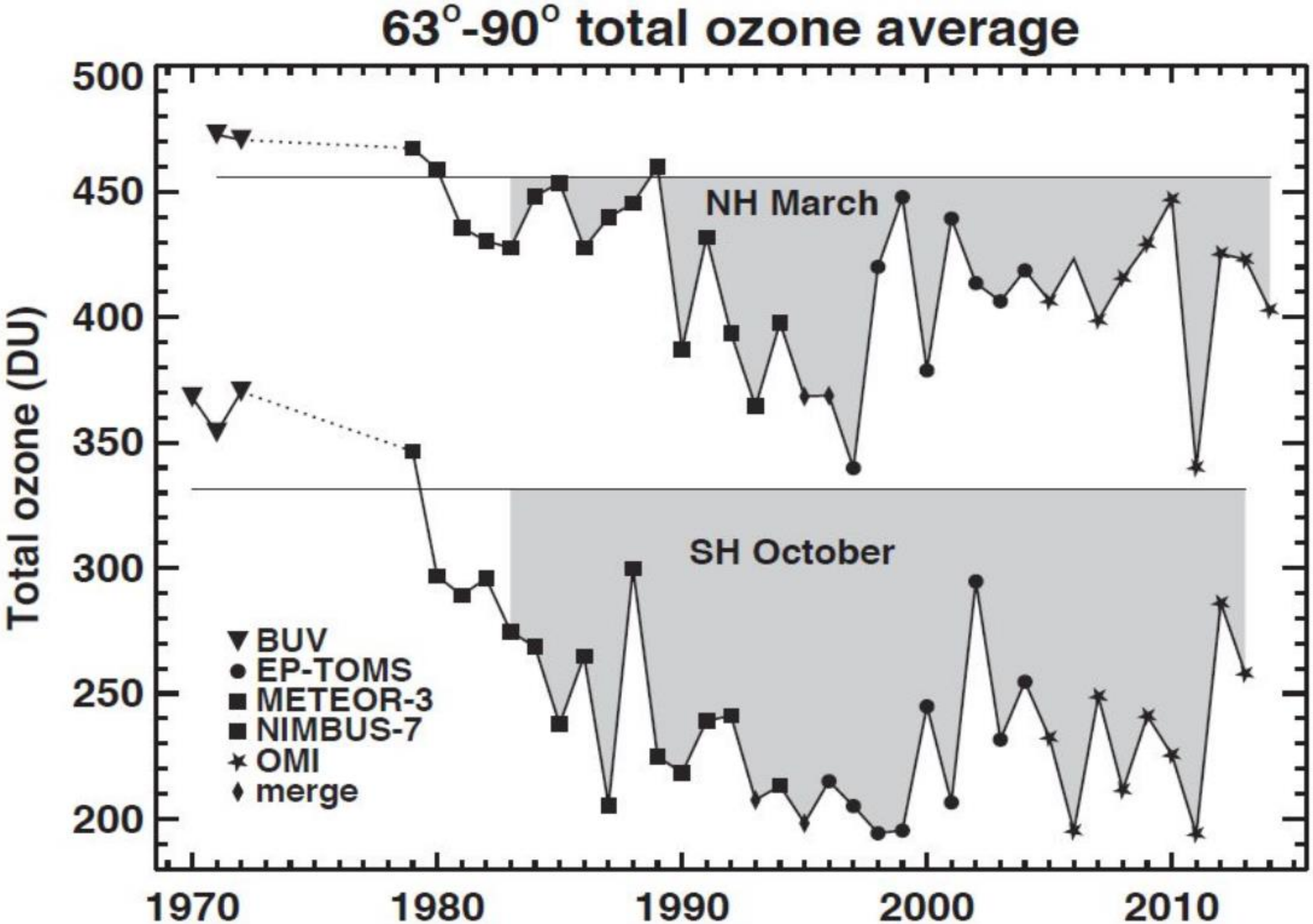
2.Lamont Doherty Observatory, Columbia University, NY





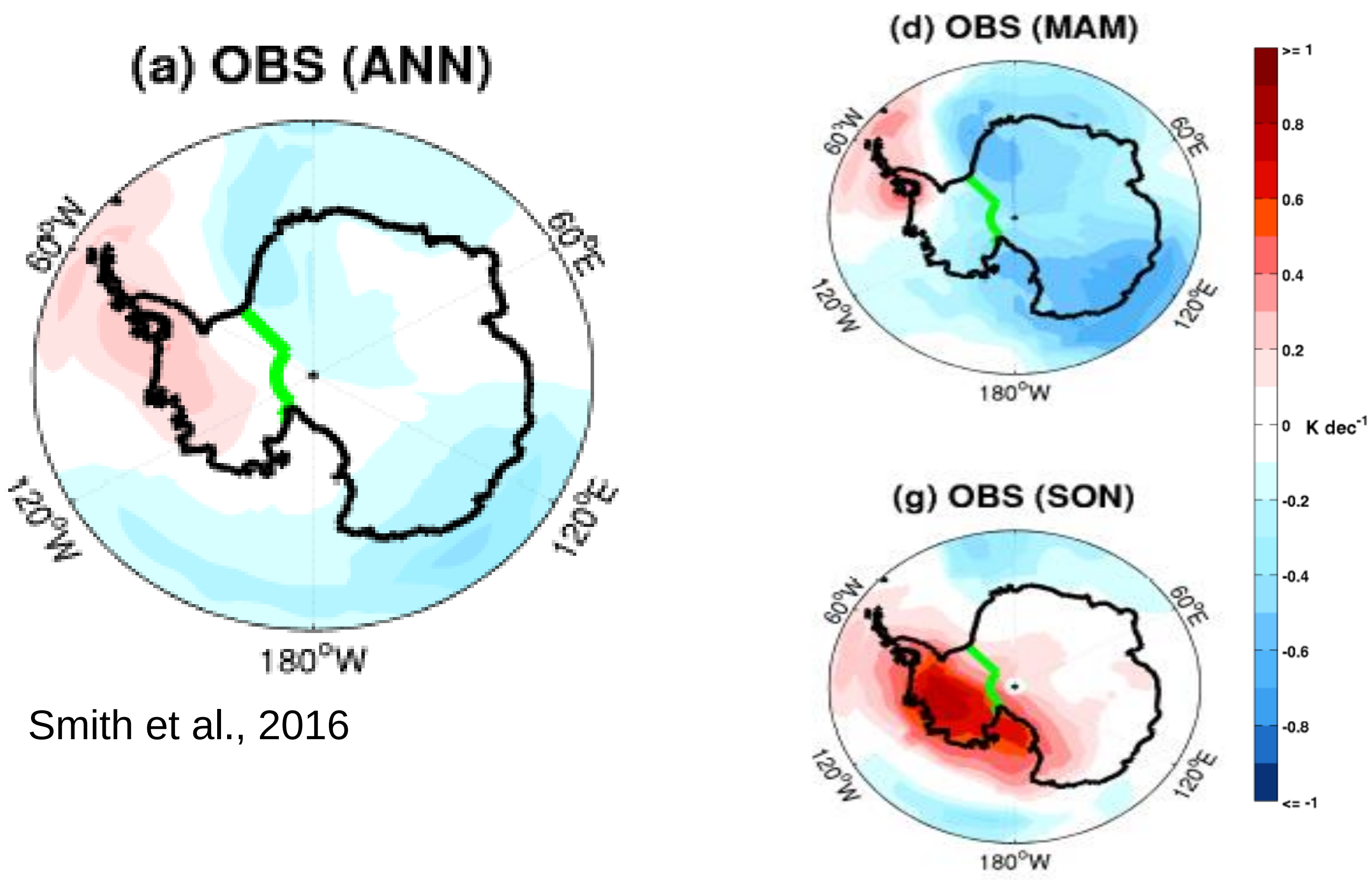


Radiative forcing of climate between 1750 and 2011
Forcing agent
Anthropogenic
Natural
Well Mixed Greenhouse Gases
CO$_2$
Other WMGHG
CH$_4$
N$_2$O
Halocarbons
Ozone
Stratospheric
Tropospheric
Stratospheric water vapour from CH$_4$
Surface Albedo
Land Use
Black carbon on snow
Contrails
Contrail induced cirrus
Aerosol-Radiation Interac.
Aerosol-Cloud Interac.
Total anthropogenic
Solar irradiance
-1
0
1
2
3
Radiative Forcing (W m^{-2})



WMO O3 assessment 2014

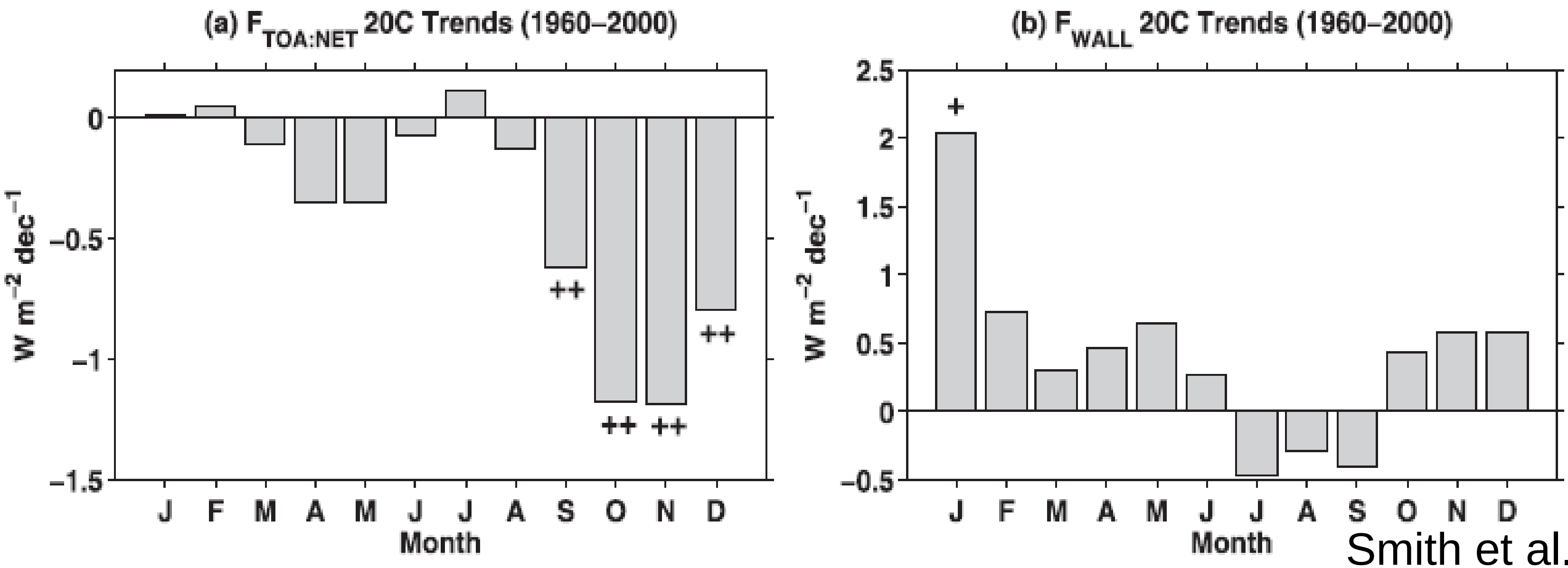
Observed surface temperature trends



Smith et al., 2016

Did ozone depletion play a role?

Effect of ozone depletion on Antarctic (atmospheric) energy budget



Smith et al., 2013

- O_3 depletion leads to energy “deficit“ at TOA

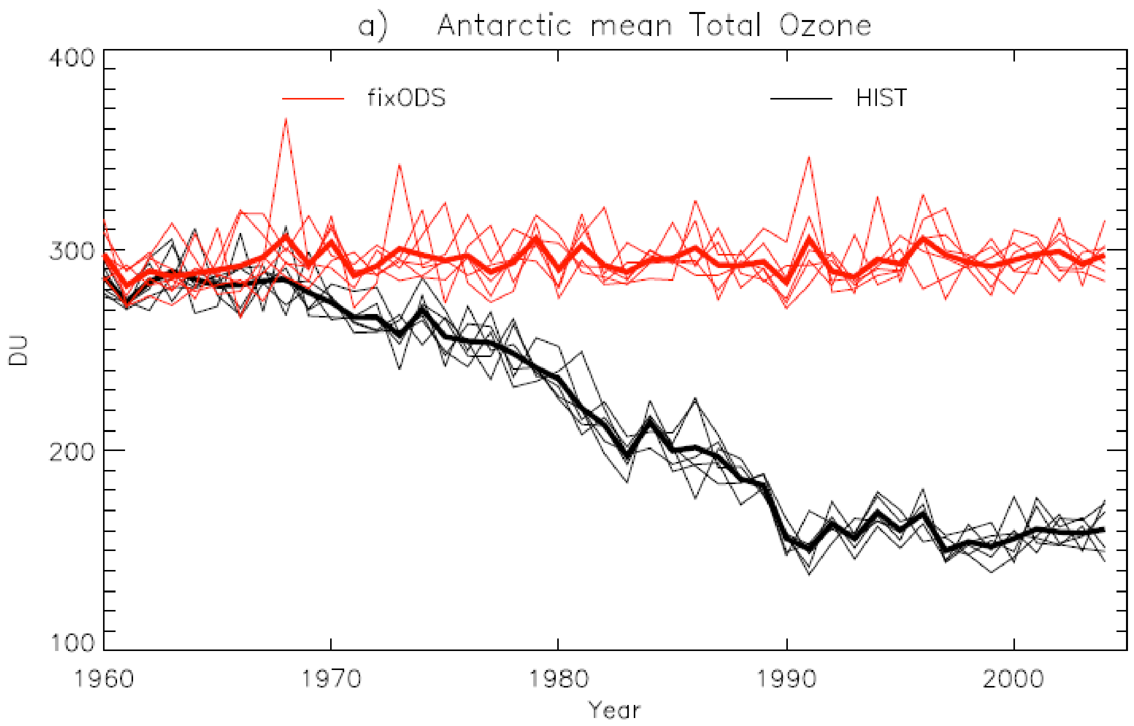
- Energy deficit balanced by increased energy flux convergence (right)

What is the impact of O_3 depletion on surface energy budget?

Method

CESM-WACCM4 model, 1.9x2.5 deg, coupled ocean and sea-ice

6 members with O3 depl (“HIST”) vs 6 members without (“fixedODS”)
(both include GHGs)



O3-hole effect : HIST-fixODS (1990-2005) OND season

Radiative forcing from stratospheric ozone depletion

Offline PORT (Conley et al., GMD 2013)

Response to perturbation p

$$\frac{dT}{dt} = H(T,C) = Q(T,C) + D(T,C),$$
$$\frac{dT_p}{dt} = H(T_p,C_p) = Q(T_p,C_p) + D(T,C).$$

$$D(T,C) = D(T_p,C_p)$$

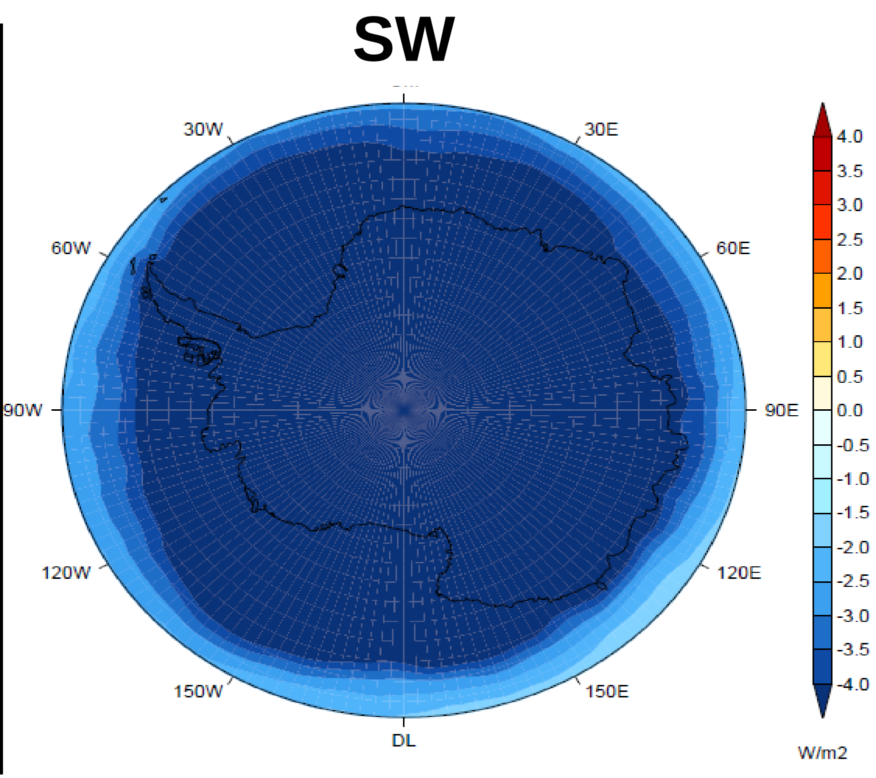
Stratospheric adjustment

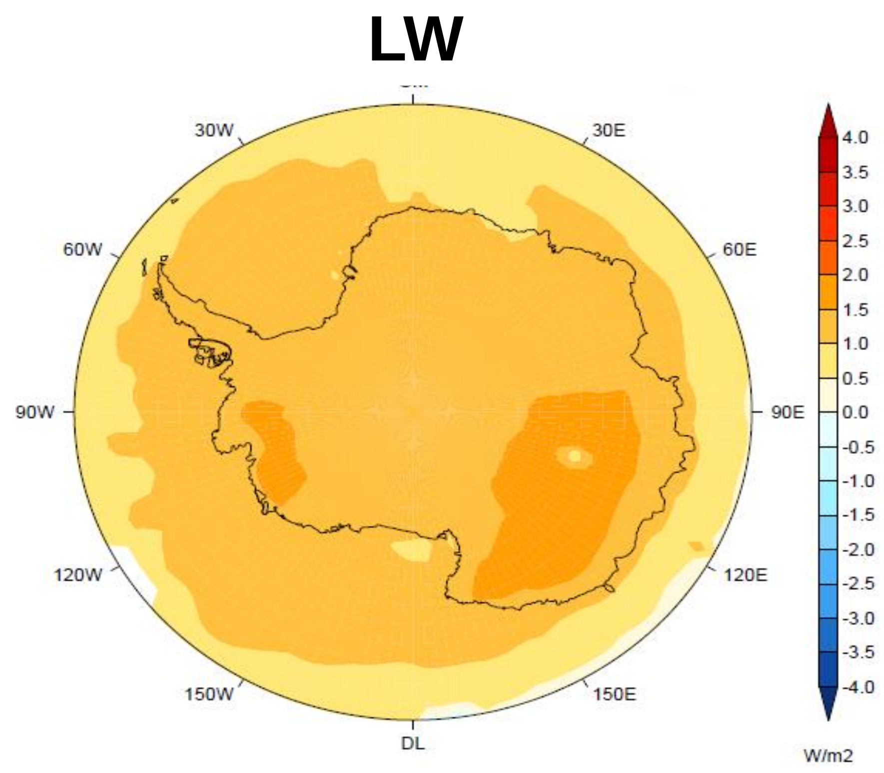
$$\frac{dT_{sa}}{dt} = H(T,C) - H(T_p,C_p) = Q(T,C) - Q(T_p,C_p).$$

-2000 vs 1955 ozone from **HIST**

-Same cloud cover, sea-ice, and RAGs (CO2,H2O)

Adjusted TOA forcing (OND)





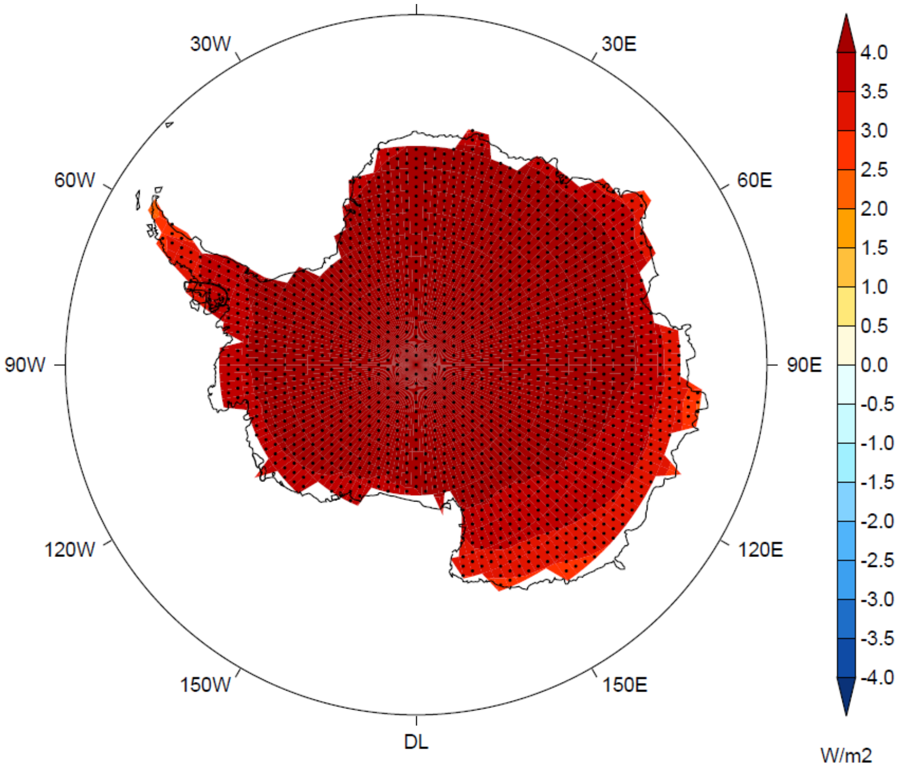
Net adjusted TOA forcing is 3-4 W/m2

What is the direct effect of O3 depletion at the surface?

Changes in surface downwelling SW

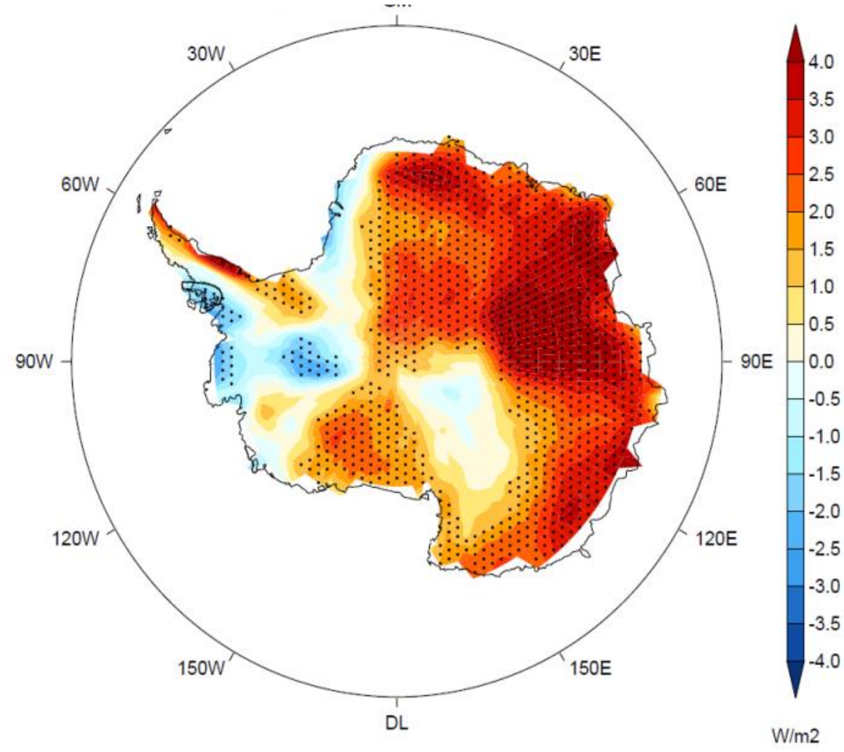
HIST-fixODS (1990-2005)

clear sky SWd



+ 3.8 W/m2

all sky SWd

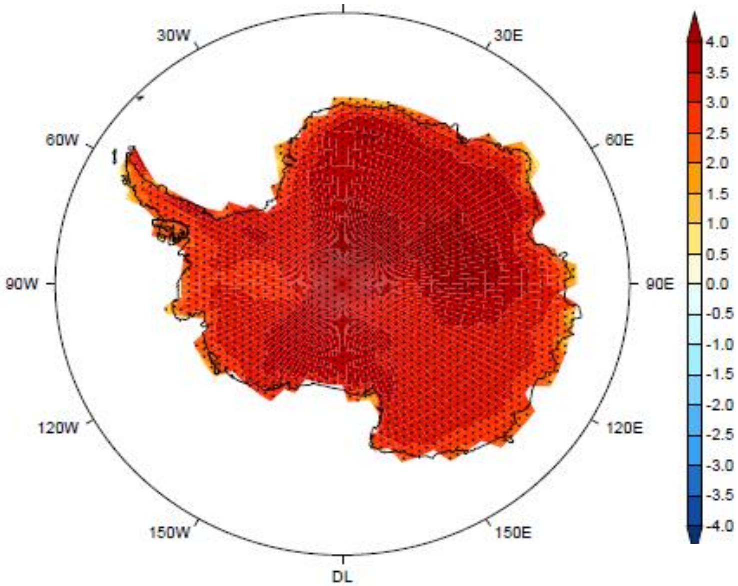


+ 1.7 W/m2

Partial compensation by clouds (near IR)

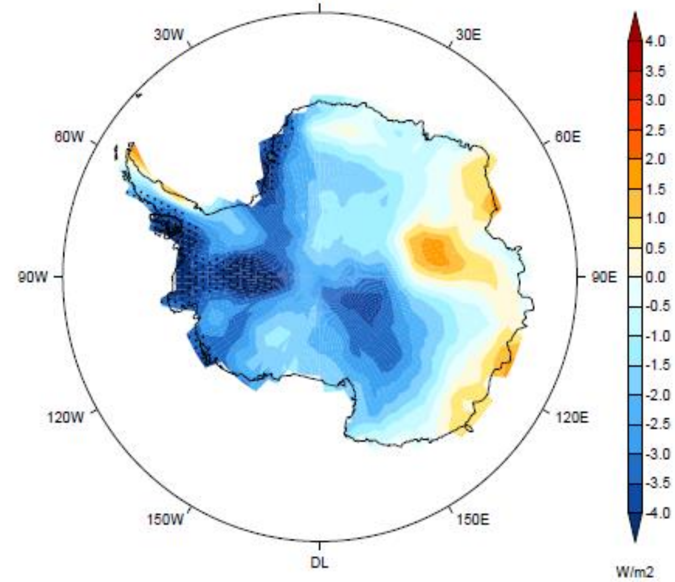
HIST-fixODS (1990-2005)

UV+VIS SWd



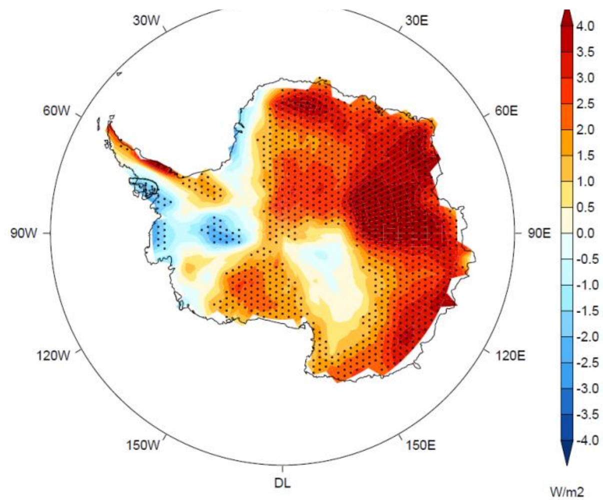
+ 3.4 W/m2

near IR SWd



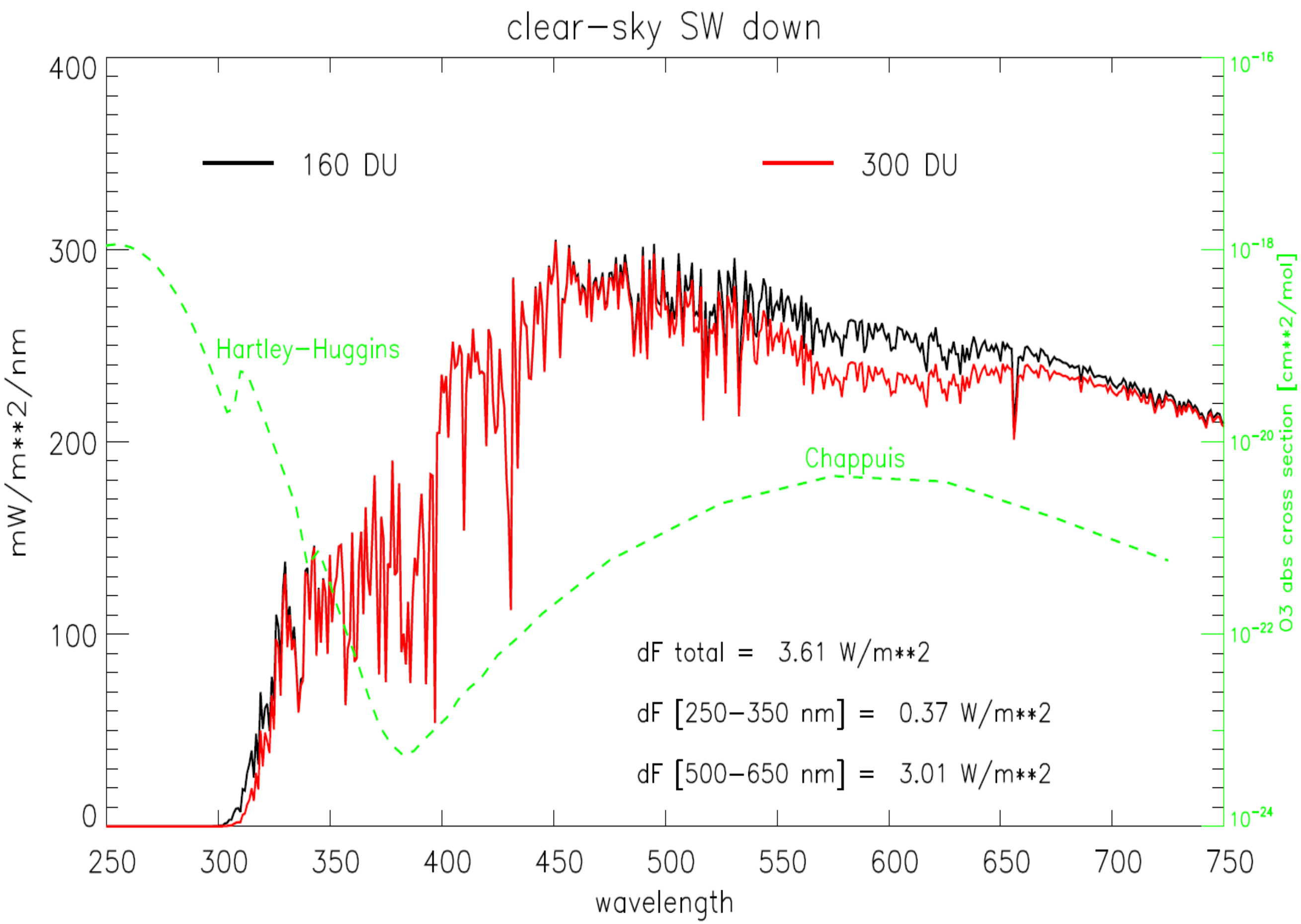
- 1.7 W/m2

all sky SWd



Is the large surface SW perturbation realistic?

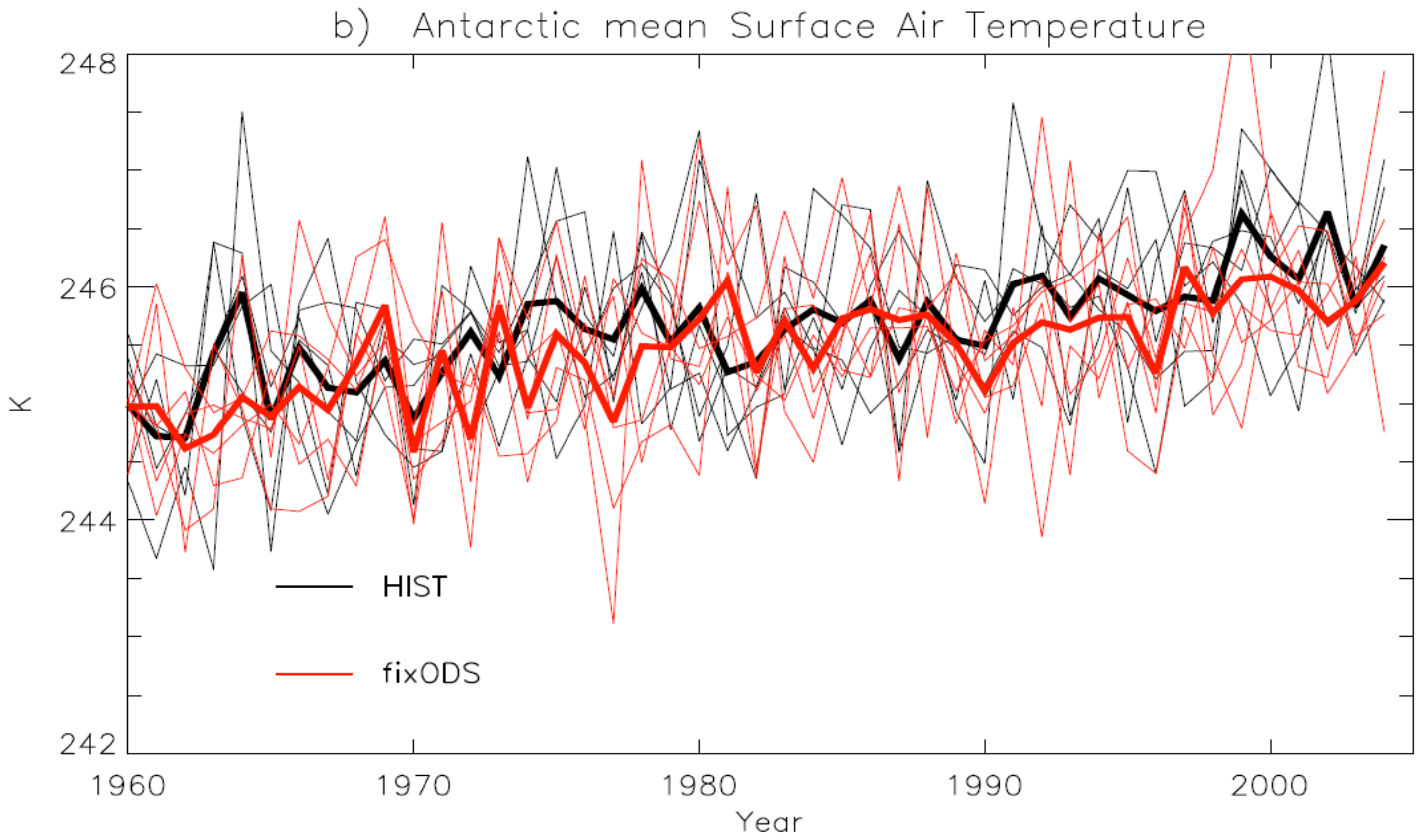
LibRadTran LbL (CCMVal, 2010)
single column, clear-sky at 80SZA, pseudo-spherical



dF of 3.61 W/m2, close to CESM-WACCM

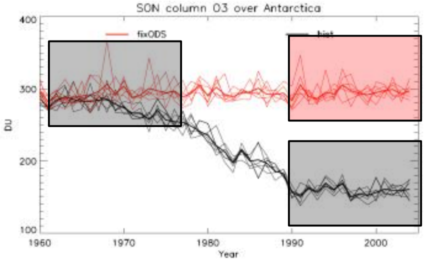
Most of dF in 500-650 nm; Chappuis Band

Does O3 depletion warm Antarctica in OND?

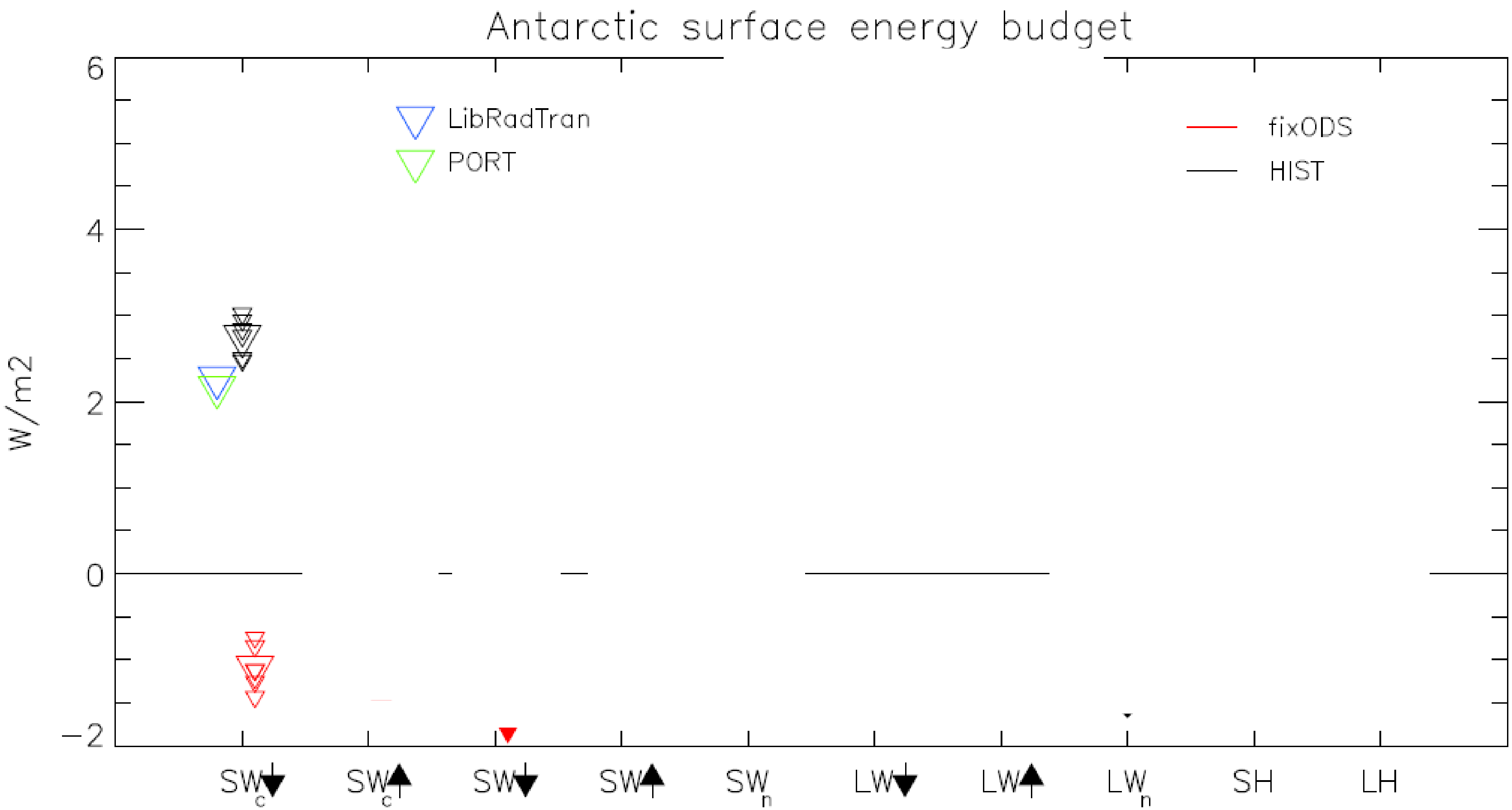


… NO!

Very similar warming trend in both HIST and fixODS



Why does O3 depletion **not** affect Antarctic surface climate?

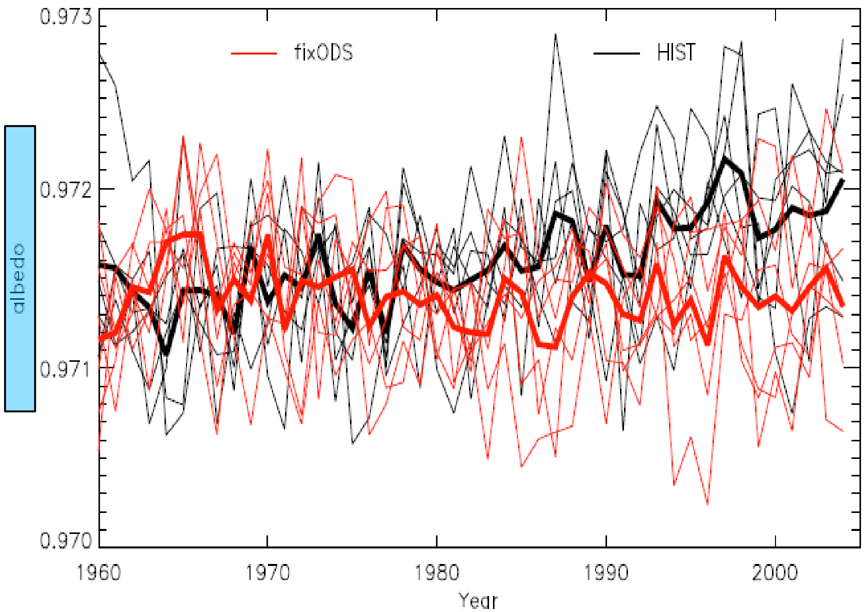


Post minus pre O3 hole period (1990-2005 clim minus 1960-1975 clim)

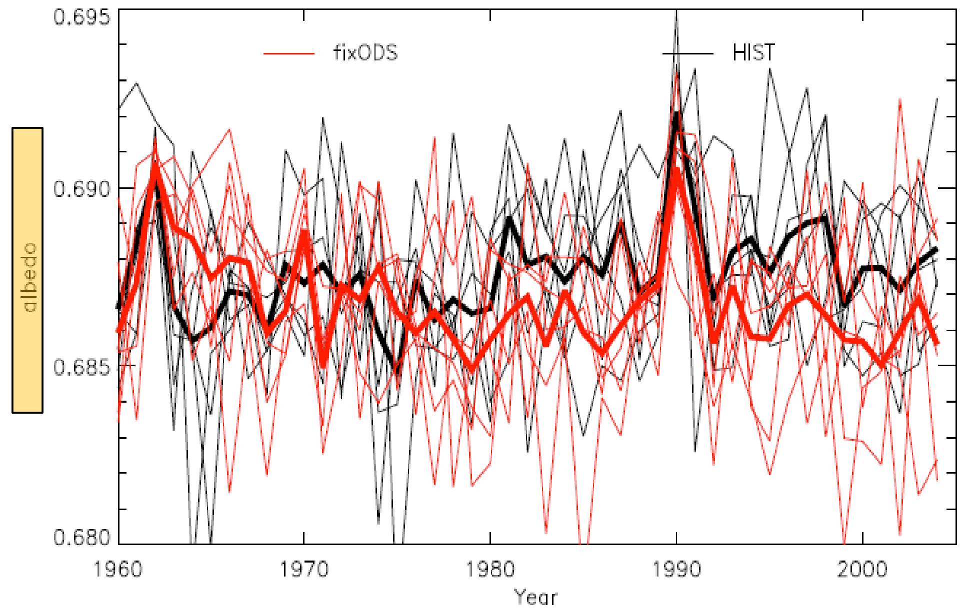
Surface albedo

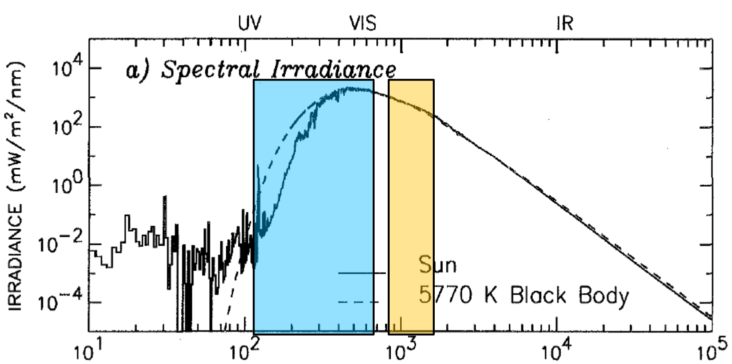
WACCM4

UV/VIS albedo

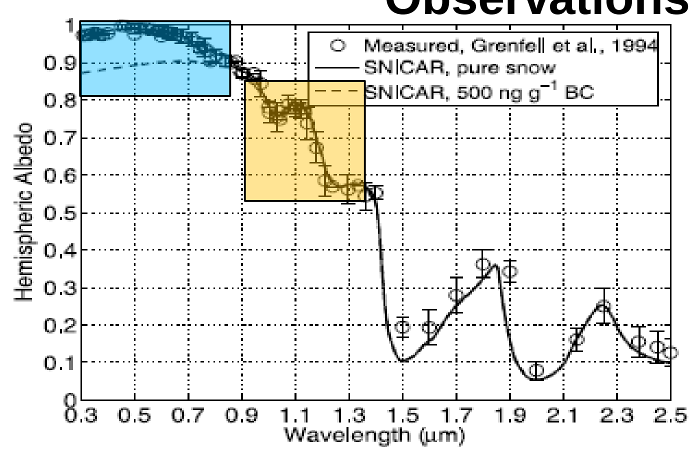


nearIR albedo

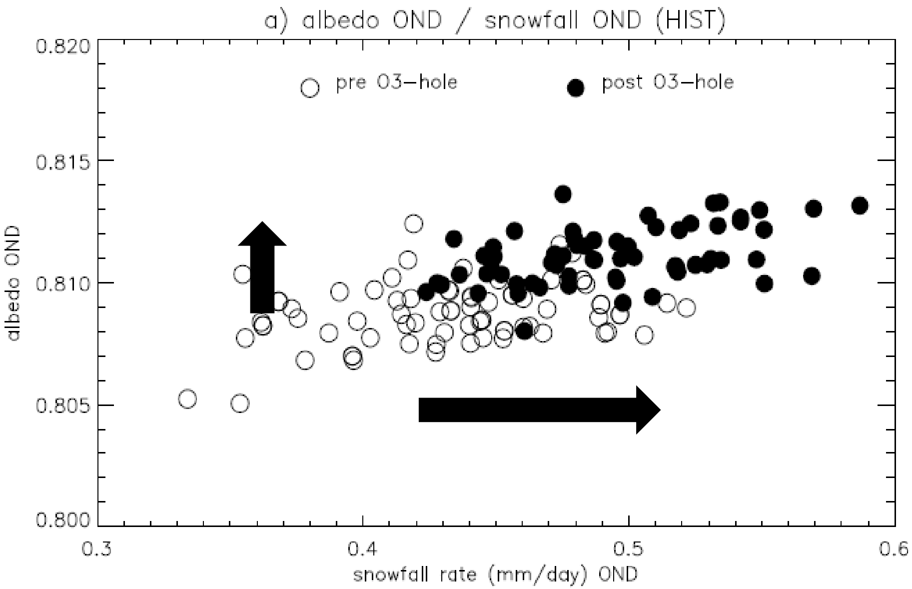


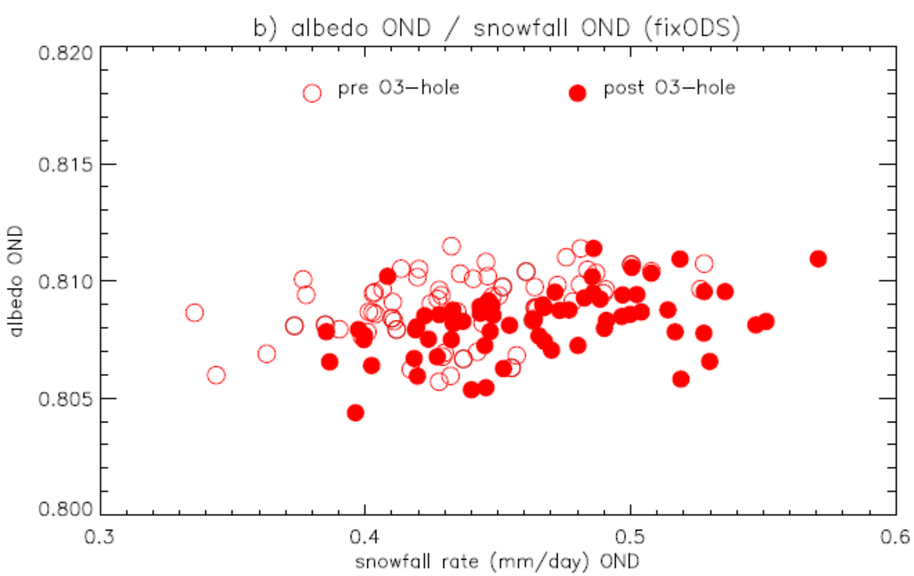


Observations



Cause of UV+VIS albedo increase

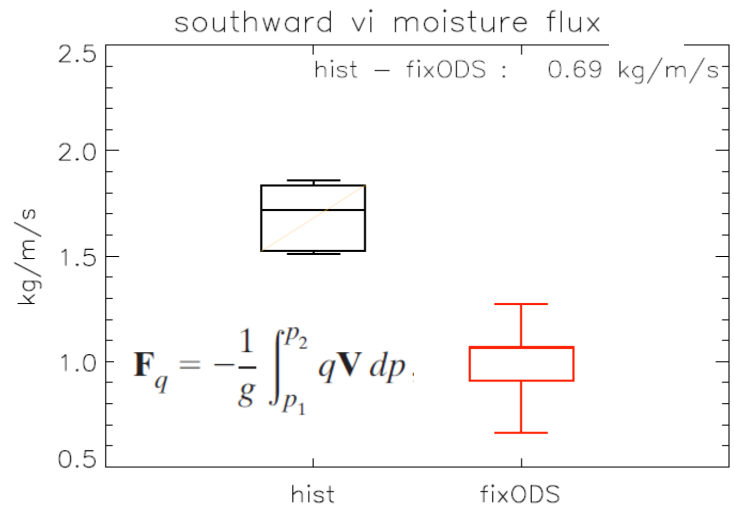




Increase in albedo (0.3%) related to ozone-hole induced **increase in Antarctic snowfall**

$$r_e(t) = \left[r_e(t-1) + dr_{e,dry} + dr_{e,wet} \right] f_{\text{old}} + r_{e,0} f_{\text{new}} + r_{e,rfz} f_{\text{rfrz}}$$

Albedo controlled by snowfall rate (snow aging scheme in CLM4)



$$\mathbf{F}_q = -\frac{1}{g} \int_{p_1}^{p_2} q\mathbf{V}\, dp$$

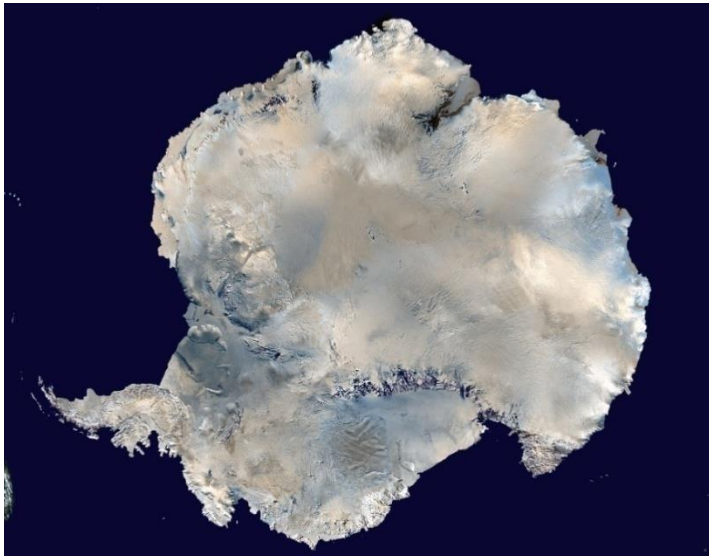
Conclusions

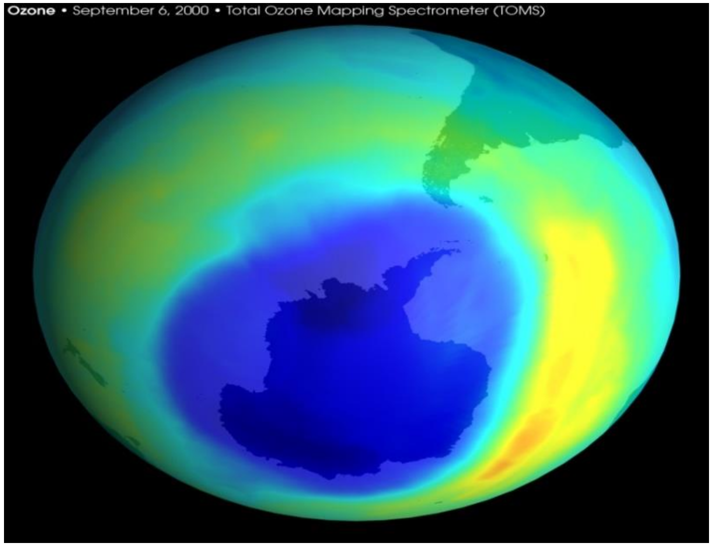
1) O_3 depletion leads to a detectable increase in downwelling SW over Antarctica, consistent with LbL calculations.

2) The SW perturbation is largely cancelled by albedo, and to lesser extent, by albedo trends induced by snowfall, which make Antarctica brighter. As a result, the net SW forcing is very small.

3) Thus, the ozone hole has a negligible radiative effect on Antarctica, and is thus unlikely to induce continental scale temperature changes.

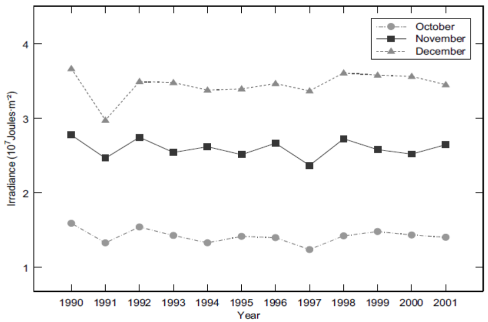
Thank you



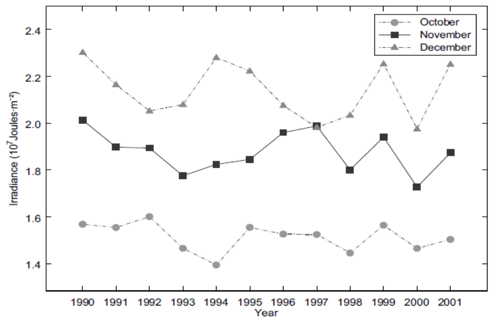

Ozone • September 6, 2000 • Total Ozone Mapping Spectrometer (TOMS)

Did downwelling SW radiation increase in the real world ?

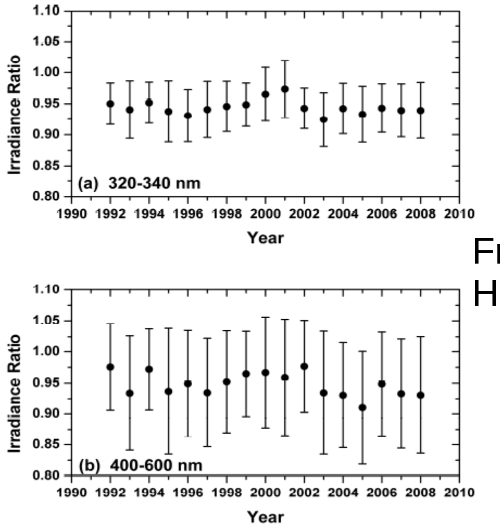
McMurdo



Ushuaia

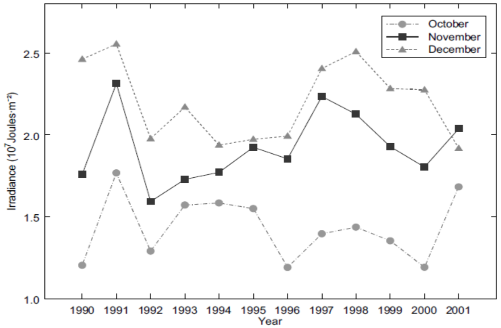


South Pole

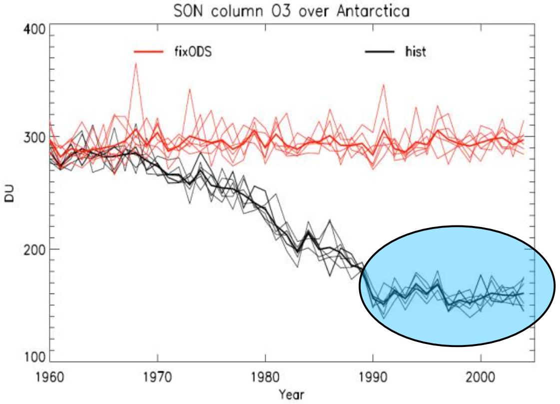


Frederick and Hodge acp 2011

Palmer



Frederick et al. 2007



… hard to say, since in-situ measurements started in 1990s

Did Antarctic albedo increase in the real world ?

Available online at www.sciencedirect.com

ScienceDirect

Remote Sensing of Environment 112 (2008) 646–667

Remote Sensing of Environment

www.elsevier.com/locate/rse

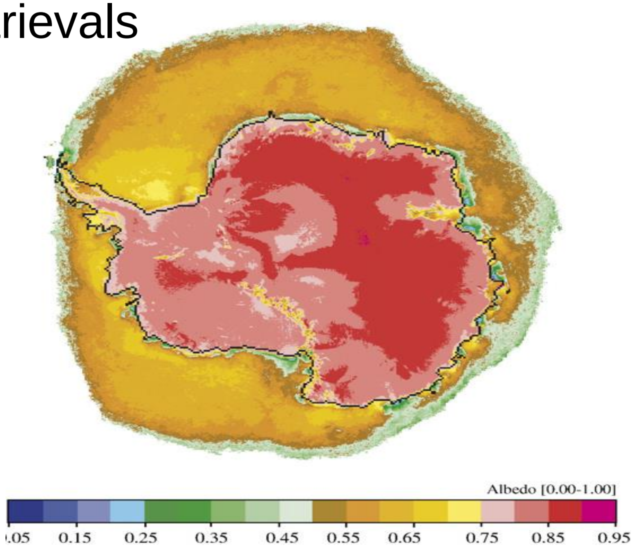
Antarctic ice sheet and sea ice regional albedo and temperature change, 1981–2000, from AVHRR Polar Pathfinder data

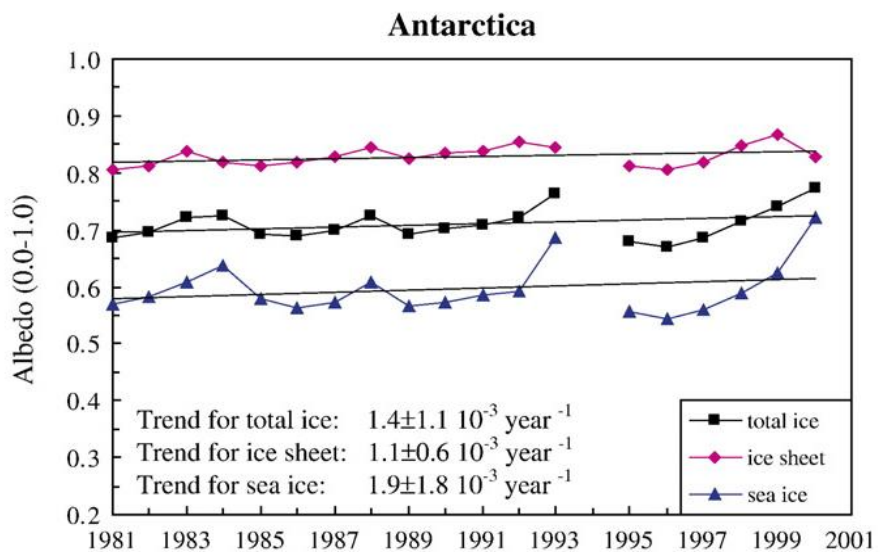
Vesa Laine

Finnish Meteorological Institute, PO Box 503, 00101 Helsinki, Finland

Received 9 January 2007; received in revised form 1 June 2007; accepted 2 June 2007

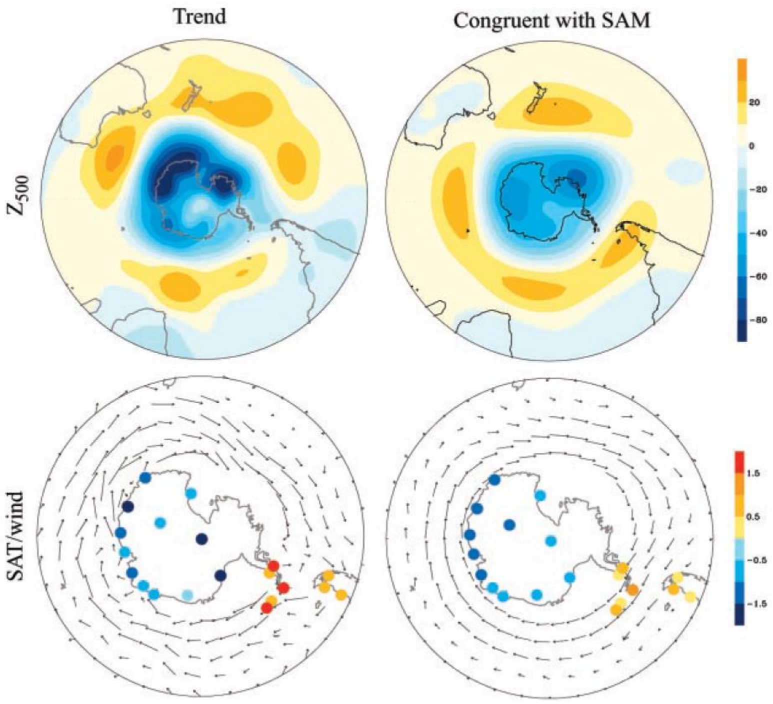
Cloud masked albedo retrievals





… positive trend for ice sheet over 1980-2000

Did ozone depletion have an impact on Antarctic climate?



Thompson and Solomon, 2002

Cooling over E-Antarctica, and warming of Peninsula
(SAM-driven pattern, …so “indirectly” induced.)

Snowfall increase over Antarctica

nature climate change

LETTERS

PUBLISHED ONLINE: 16 MARCH 2015 | DOI: 10.1038/NCLIMATE2574

Increase in accumulation with warming

Consistent evidence of increasing Antarctic accumulation with warming

Katja Frieler[1]*, Peter U. Clark[2], Feng He[2,3], Christo Buizert[2], Ronja Reese[1,4], Stefan R. M. Ligtenberg[5], Michiel R. van den Broeke[5], Ricarda Winkelmann[1,4] and Anders Levermann[1,4]

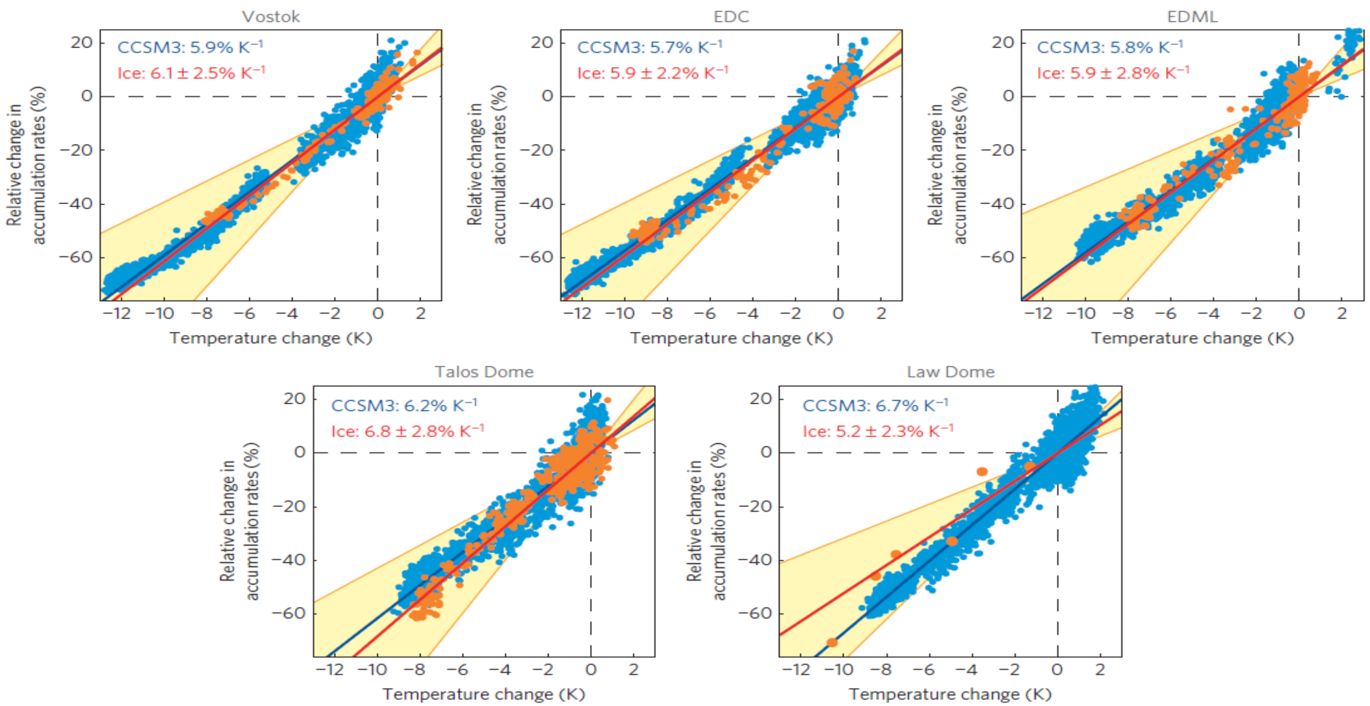


Figure 1 | Changes in local accumulation rates and temperatures derived from ice cores (orange) and CCSM3 palaeo-simulations (blue, decadal averages) at the ice-core sites. Changes in accumulation and temperature are described in comparison to a core-specific pre-industrial reference level (see Supplementary Information). Thick solid lines are derived by linear regression assuming that the intercept is zero (orange lines for ice-core data and blue lines for simulations, sensitivities are given in each panel including the 2σ uncertainty range of the sensitivities derived from the ice cores). The shaded area describes the uncertainty range of the ice-core sensitivities.

Negative snowfall–albedo feedback?

Can **snowfall reduce** the **positive snow-albedo feedback**?

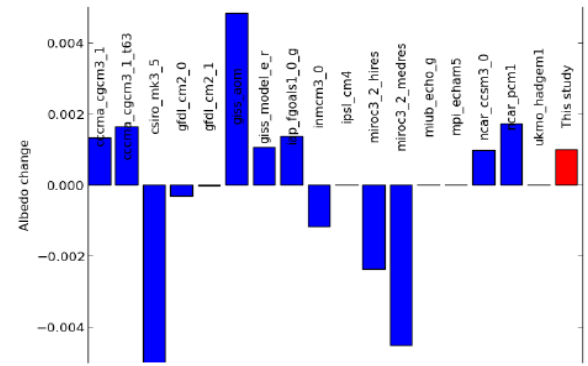
nature climate change

LETTERS

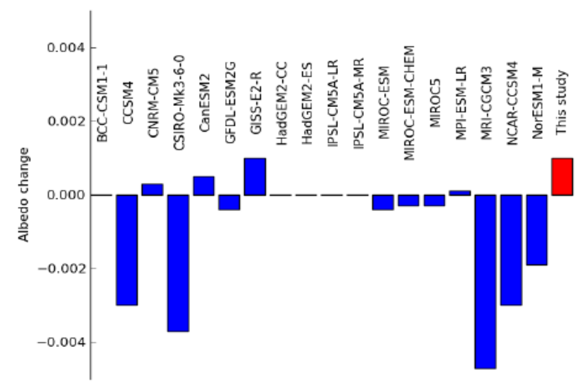
PUBLISHED ONLINE: 1 JULY 2012 | DOI: 10.1038/NCLIMATE1590

Inhibition of the positive snow-albedo feedback by precipitation in interior Antarctica

G. Picard[1]*, F. Domine[1,2], G. Krinner[1], L. Arnaud[1] and E. Lefebvre[1]



b)

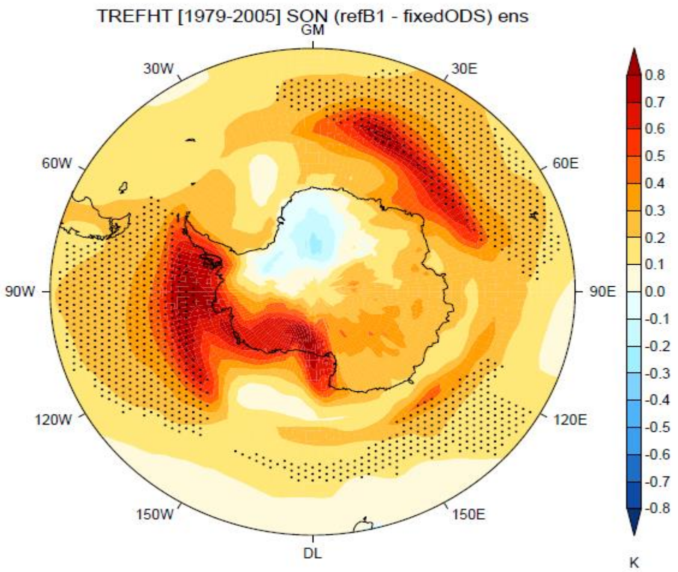


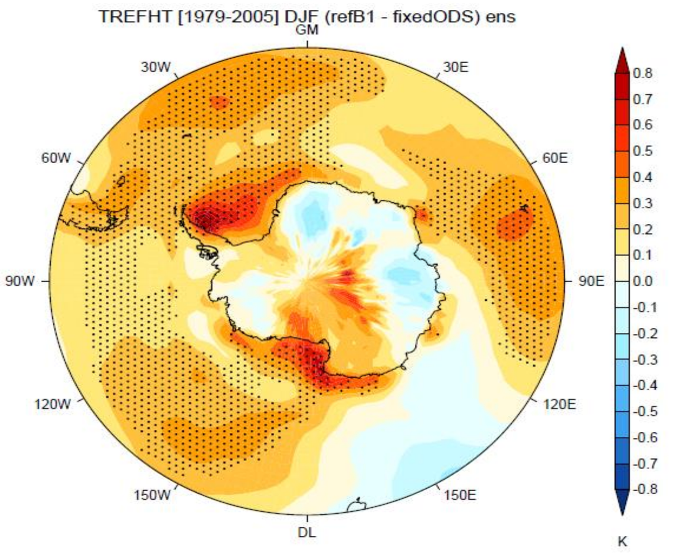
- Projected future **increase** in **precipitation** can **increase** snow **albedo** by 0.4% on average over 21st century and **overcompensate** expected **albedo decrease** owing to **warming**

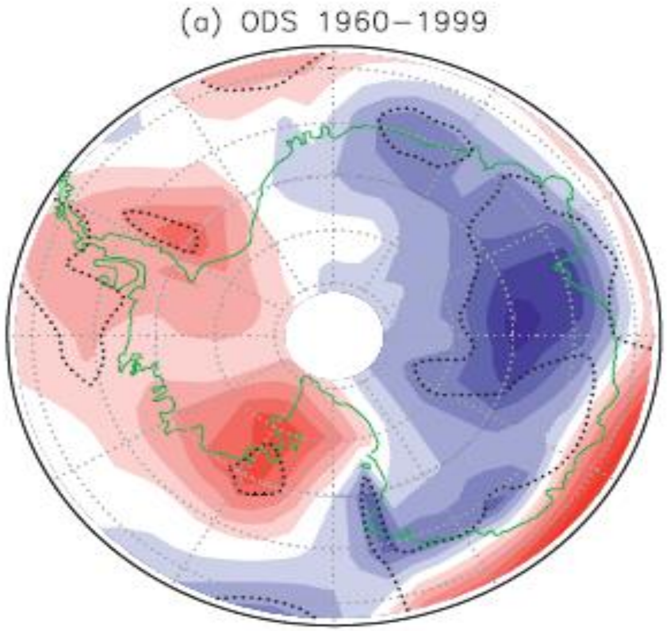
- compensation seems model dependent

Supplementary Figure 5. Albedo change in Antarctica (above 2000m) predicted by models in the Coupled Model Intercomparison Project a) *CMIP3* under SRES A1B scenario and b) CMIP5 under RCP4.5 scenario between the present (1986-2005) and future (2080-2099). The increase of albedo estimated in this study at Dome C is shown in red.

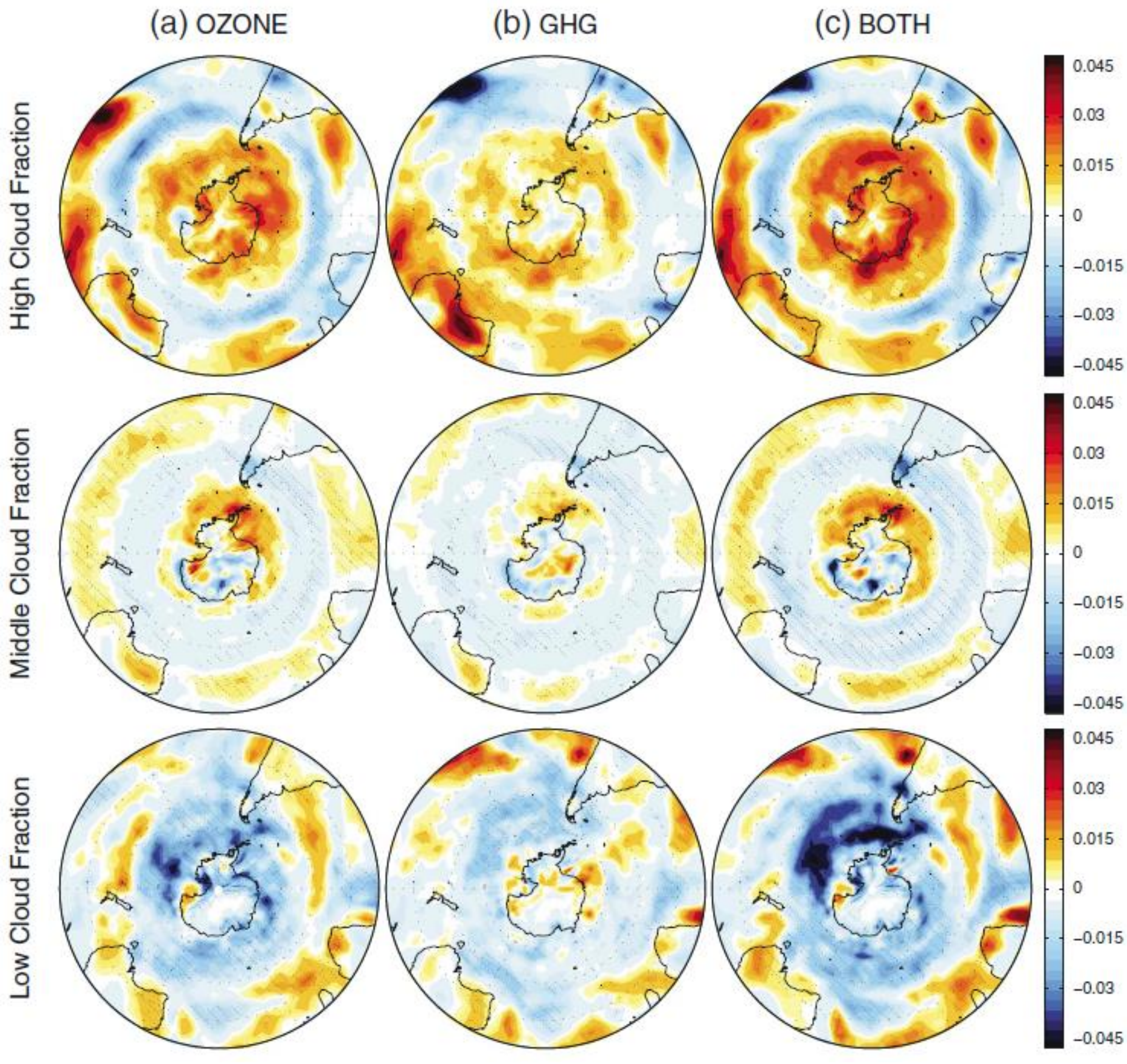
Does O3-hole "cool" E-Antarctica?







McLandress et al., 2011



Grise et al., 2013