Recent Antarctic Atmospheric Warming and Climate Feedbacks

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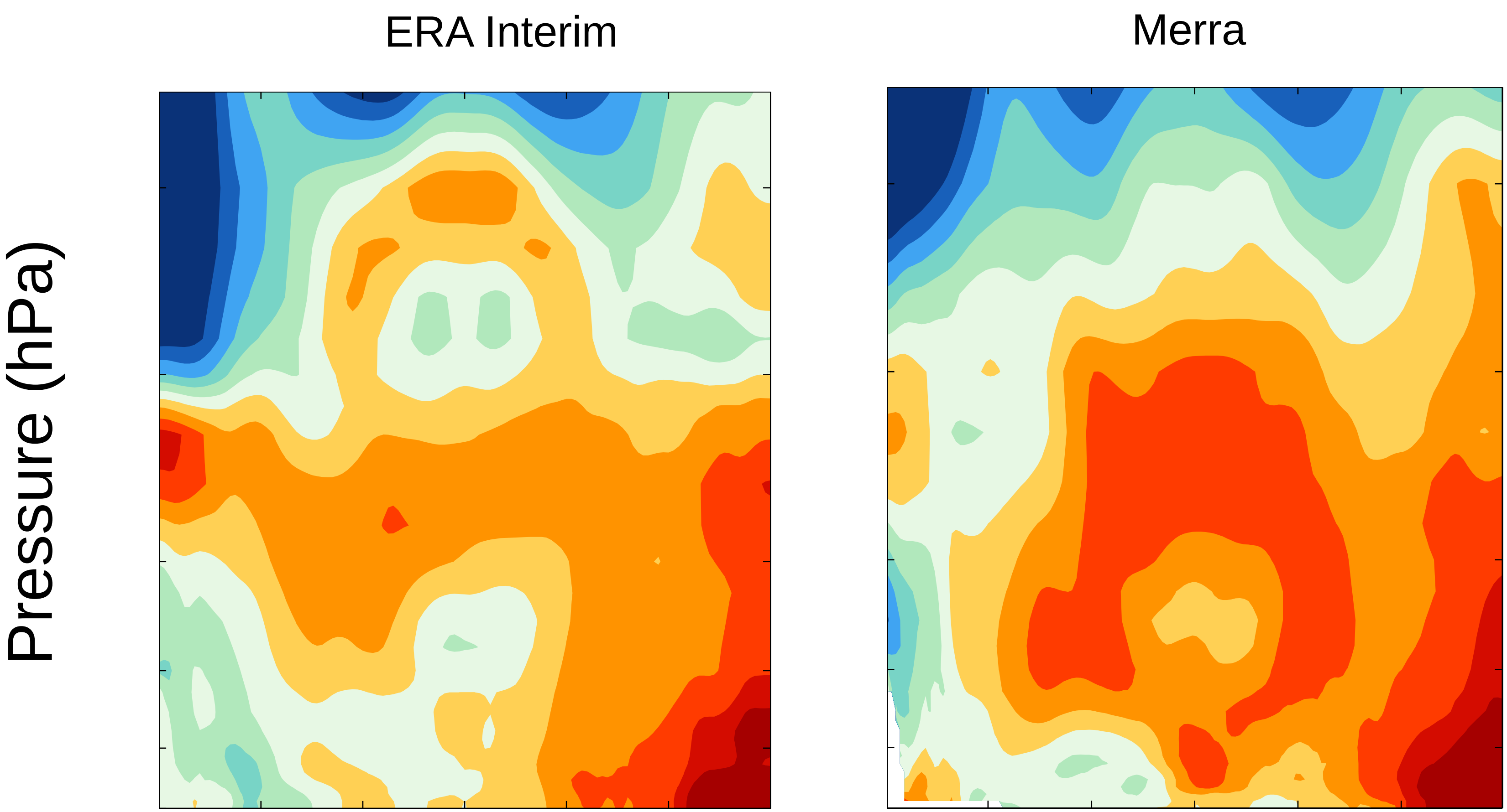
Gerard Roe, Hansi Singh

Atmospheric Zonal Mean Temperature Trend 1979-2013



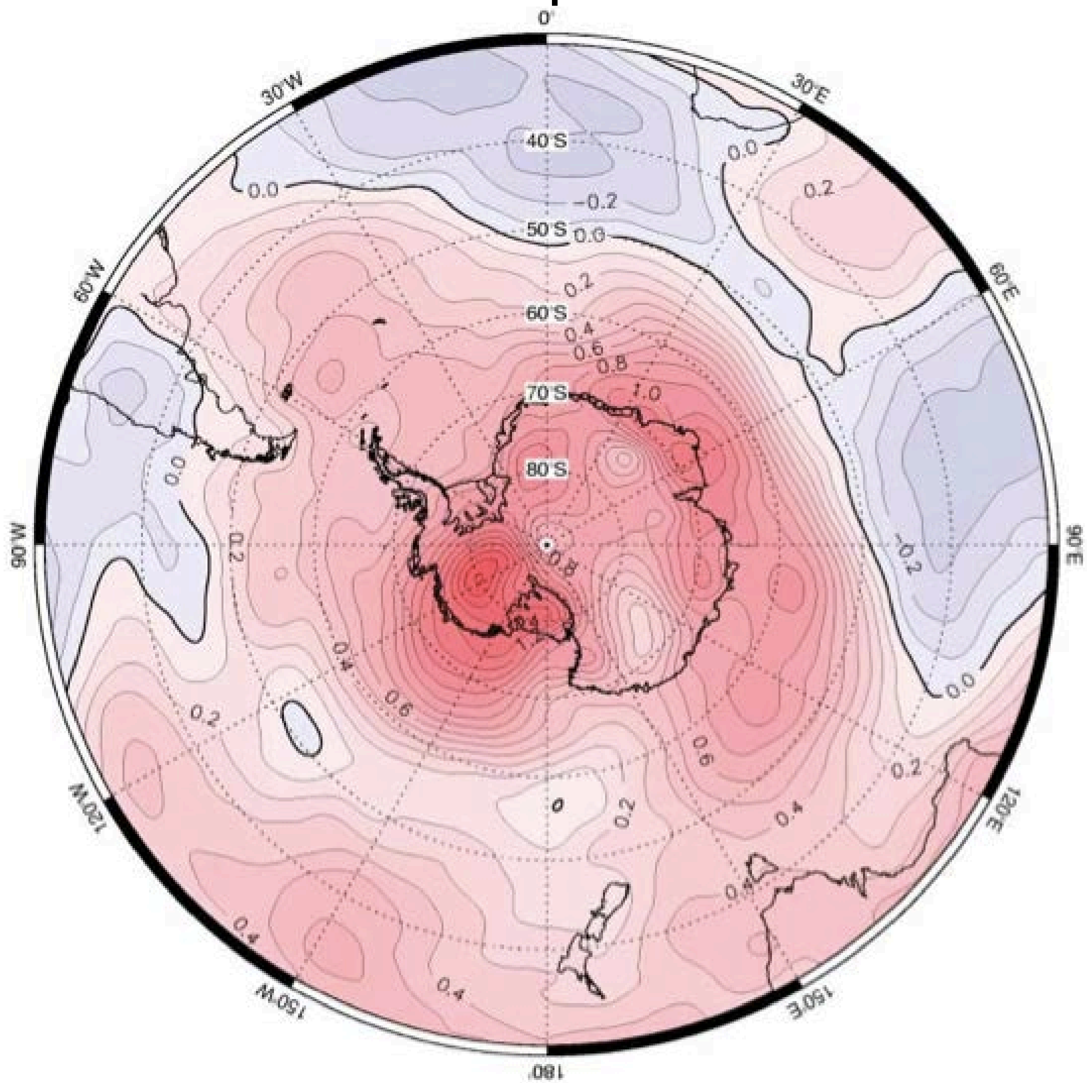
Latitude

Polar Amp.
Not above
~300 hPa

Latitude

° C per decad

500 hPa Temperature Trend in winters 1979-2001



\“the four members of the ensemble showed a large variability in the Antarctic tropospheric temperature trends, indicating the difficulty of reproducing climate change across the region. However, on average, the runs had a maximum warming in the midtroposphere”

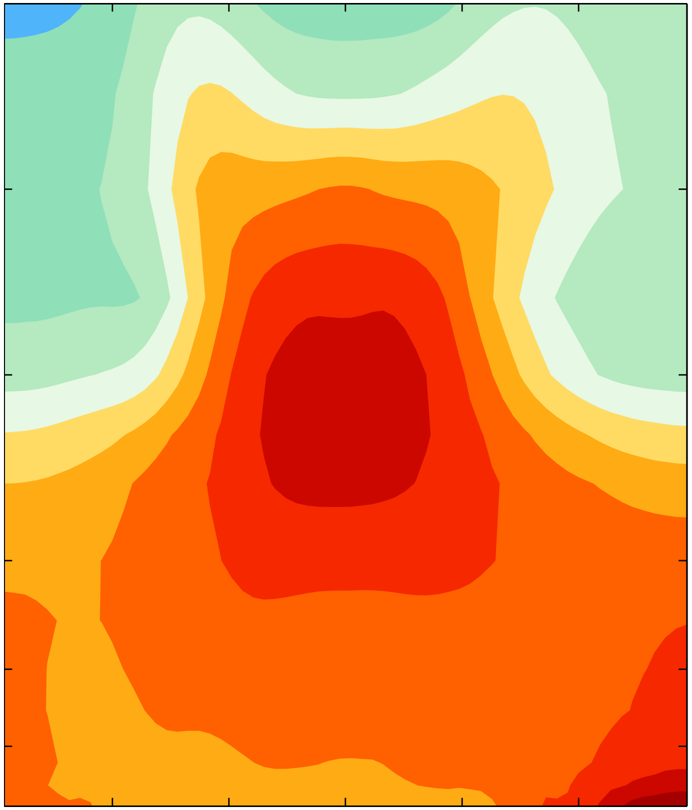
Later attributed to increase in PSC (Lachlan-Cope et al 2009) & Tropical teleconnections (Ding et al, 2011, and Screen and Simmonds, 2012)

From ERA in Turner et al 2006

Do models warm most aloft in the Antarctic from CO2 alone?

Not Seen in Response in CMIP5 Models

Tropospheric Warming From 4XCO2



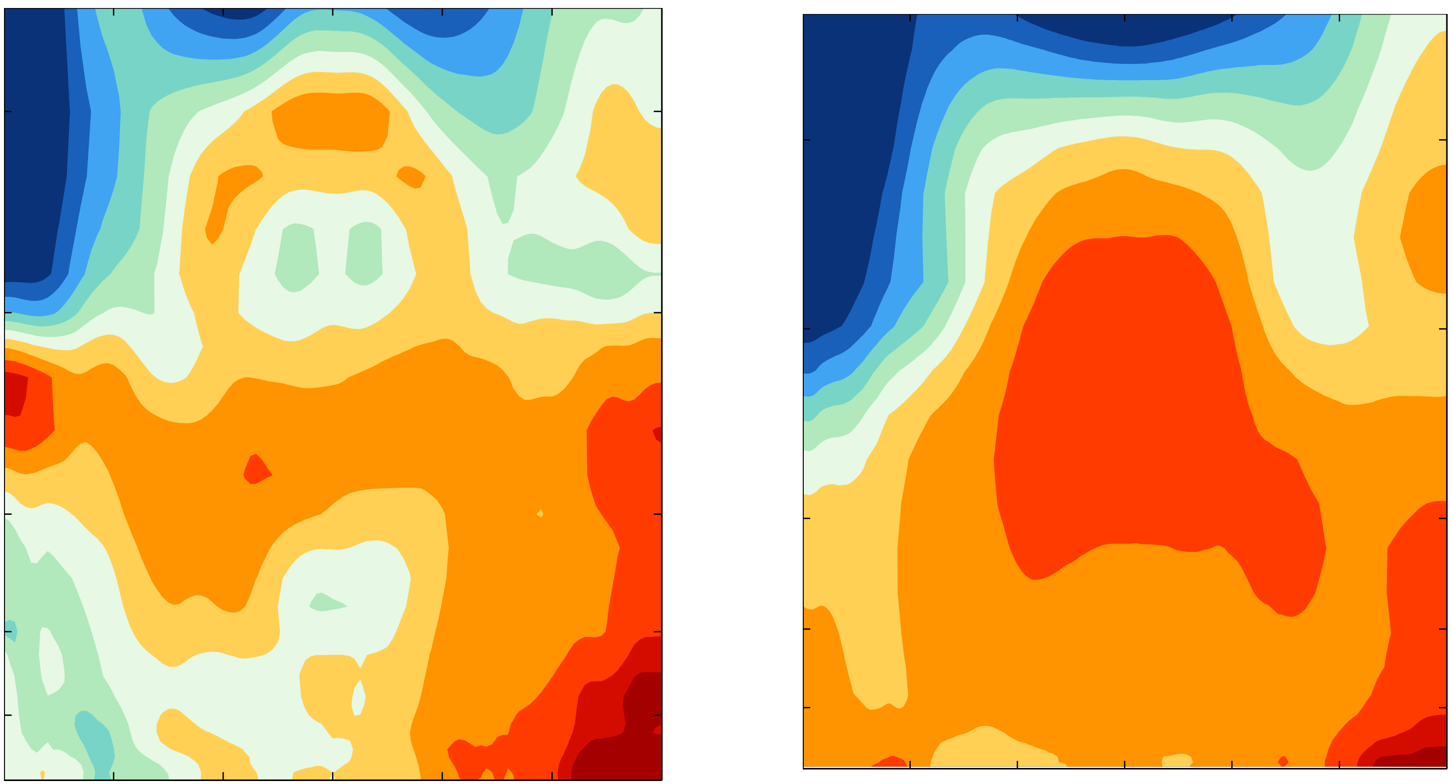
K

Computed for abrupt 4XCO2 CMIP5 after 140 yrs relative to Pre Industrial

Do models warm most aloft in the Antarctic with all forcing?

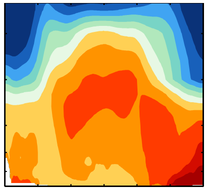
Atmospheric Zonal Mean Temperature Trend 1979-2013

in Annual Means



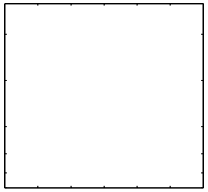
Atmospheric Zonal Mean Temperature Trend 1979-2013

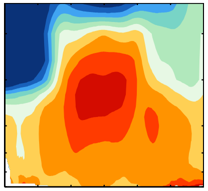
CESM1-CAM5 Large Ensemble



Pressure (hPa)

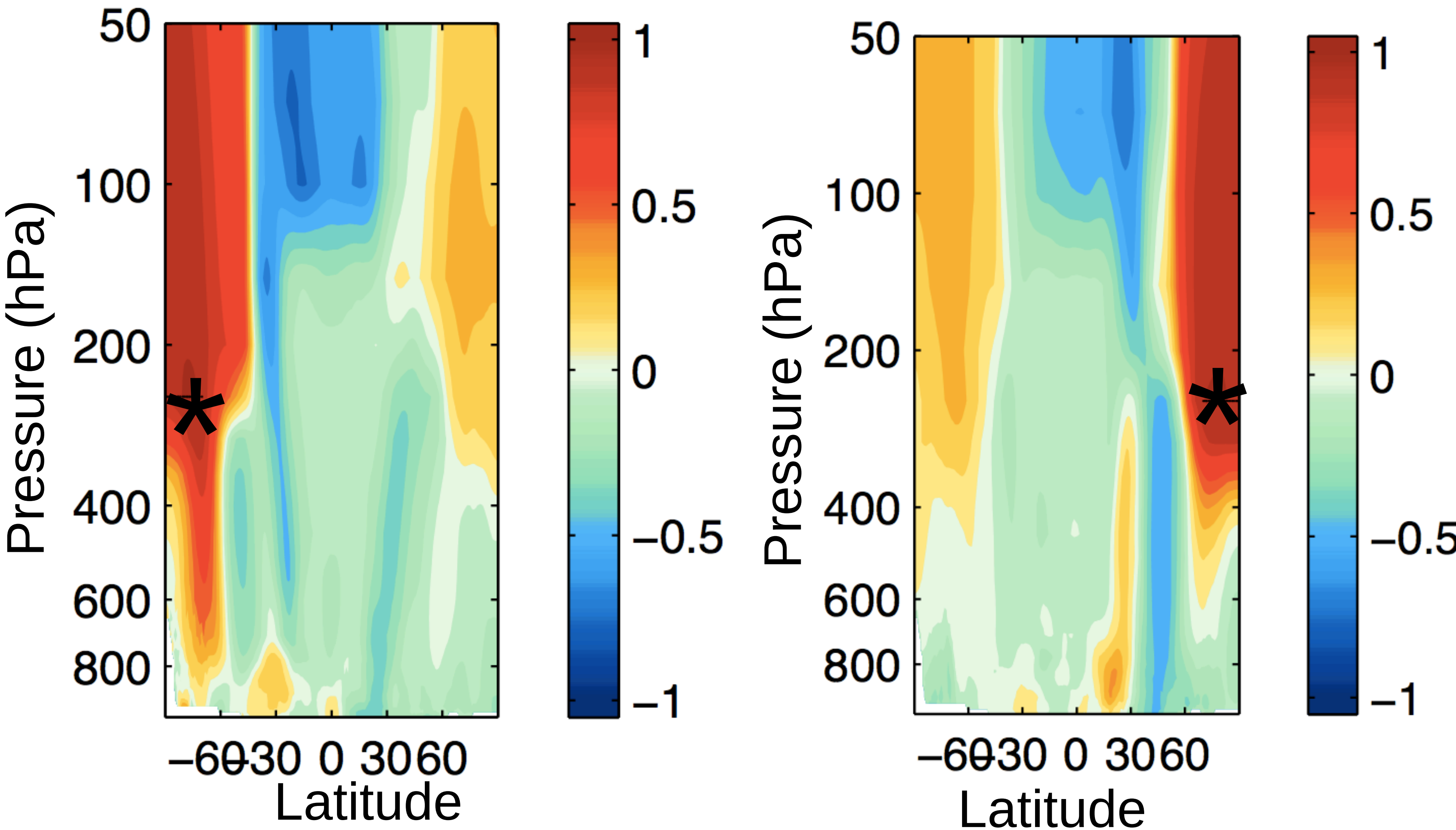
NO!



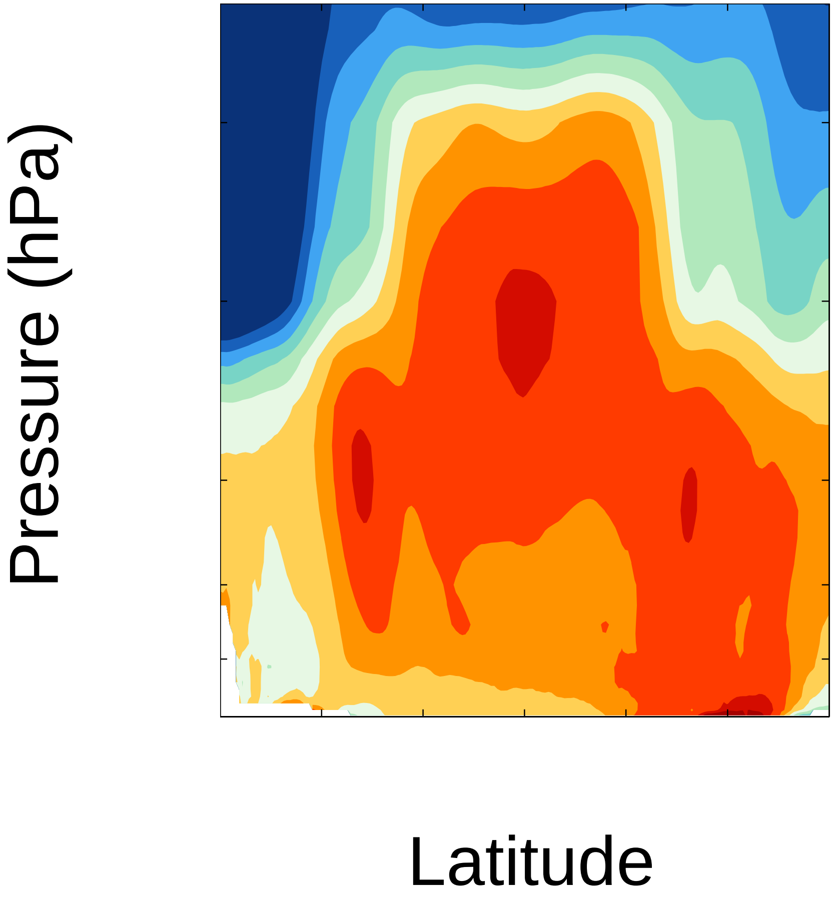


Latitude

Correlation Across LE Trends in Previous Figure with an Average of the Polar Tropopause Temperature (indicated by the black star)



CESM1.1 GAMIP Run 1979-2005 Temperature Trends



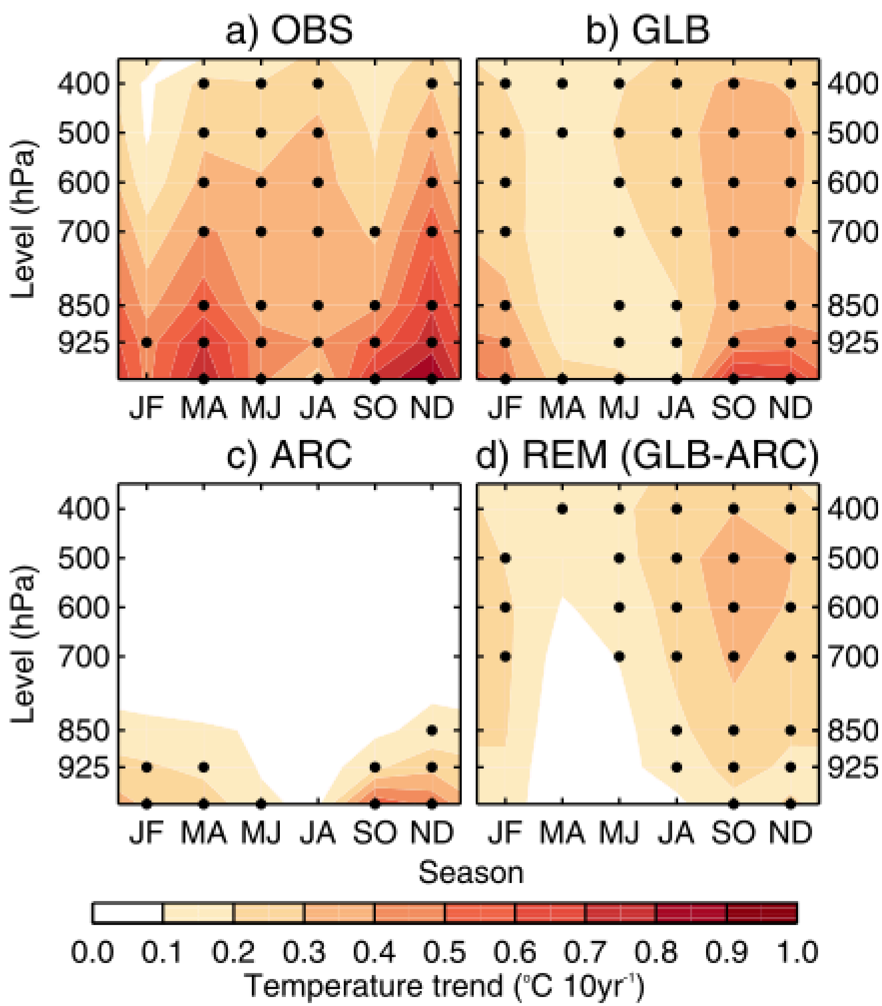
Screen et al (2012) about **attribution of Arctic (north of 67N)** Air Temperature Trends 1978-2008

Avg. of Four Reanalyses

AGCM with prescribed observed SST, sea ice and forcings

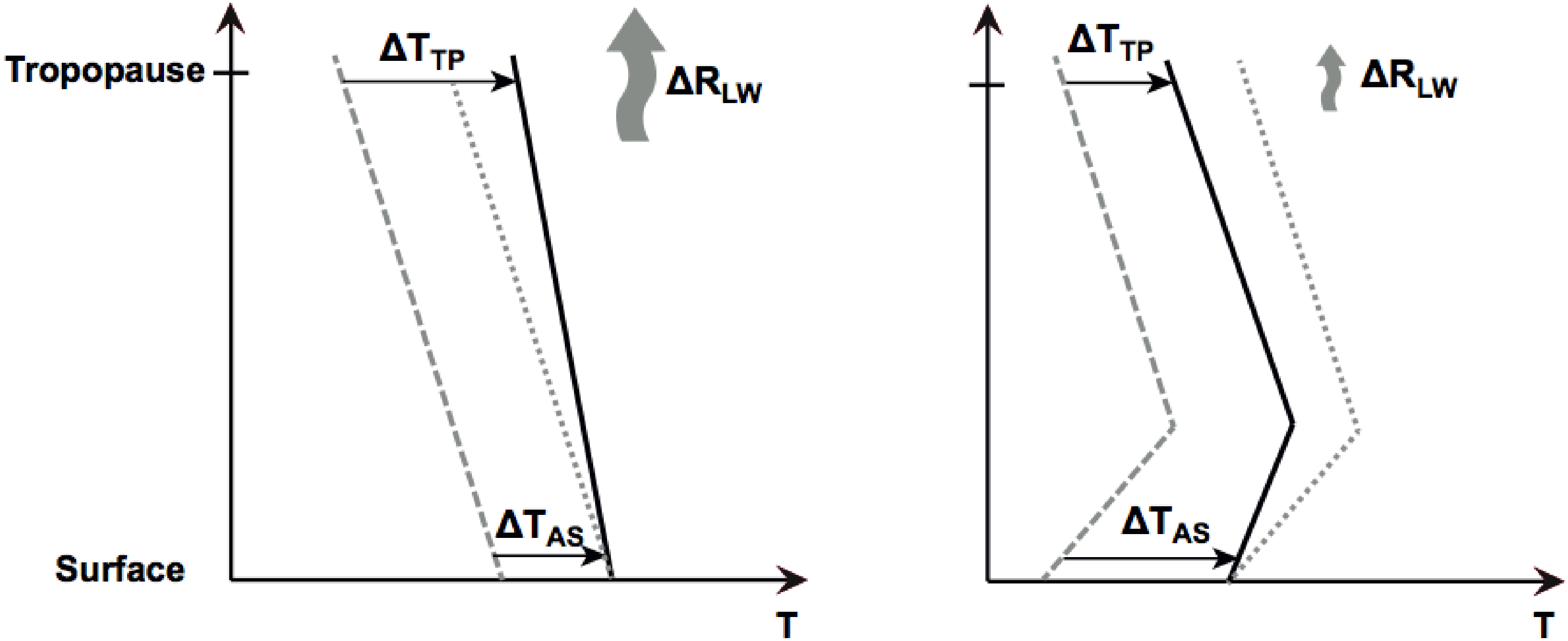
AGCM with prescribed observed ARCTIC SST sea ice ONLY

Residual



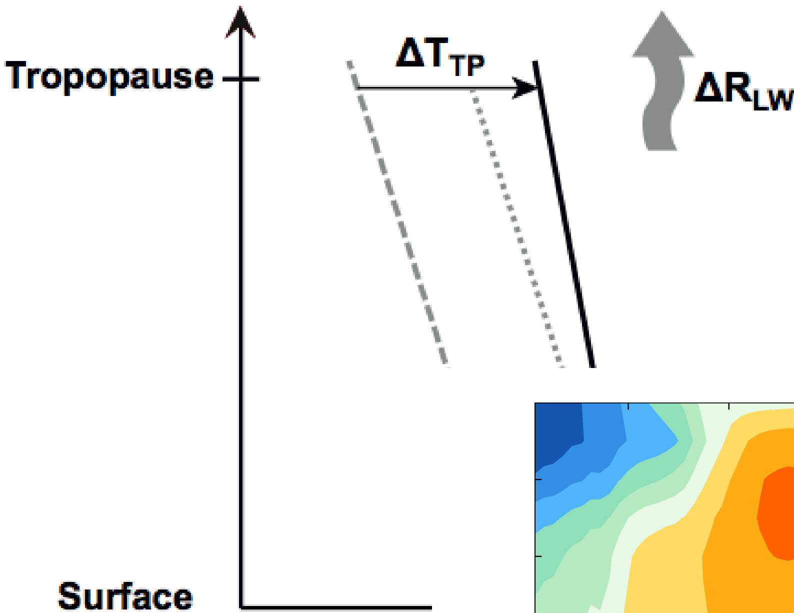
Conclusion: Warming Aloft is from remote SST trends. They further show that anthropogenic forcings contribute to summer warming aloft.

Tropics (negative λ_{LR}) Poles (positive λ_{LR})

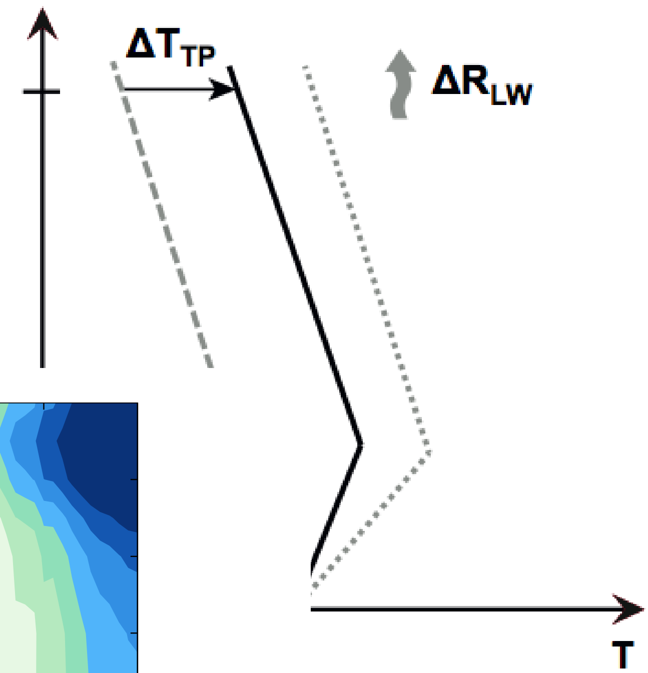


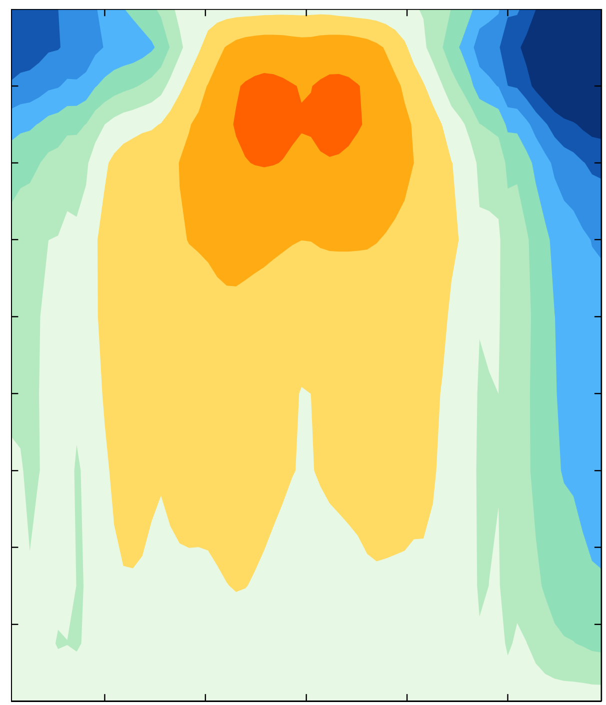
Pithan and Mauritsen (2013)

Tropics (negative λ_{LR})



Poles (positive λ_{LR})

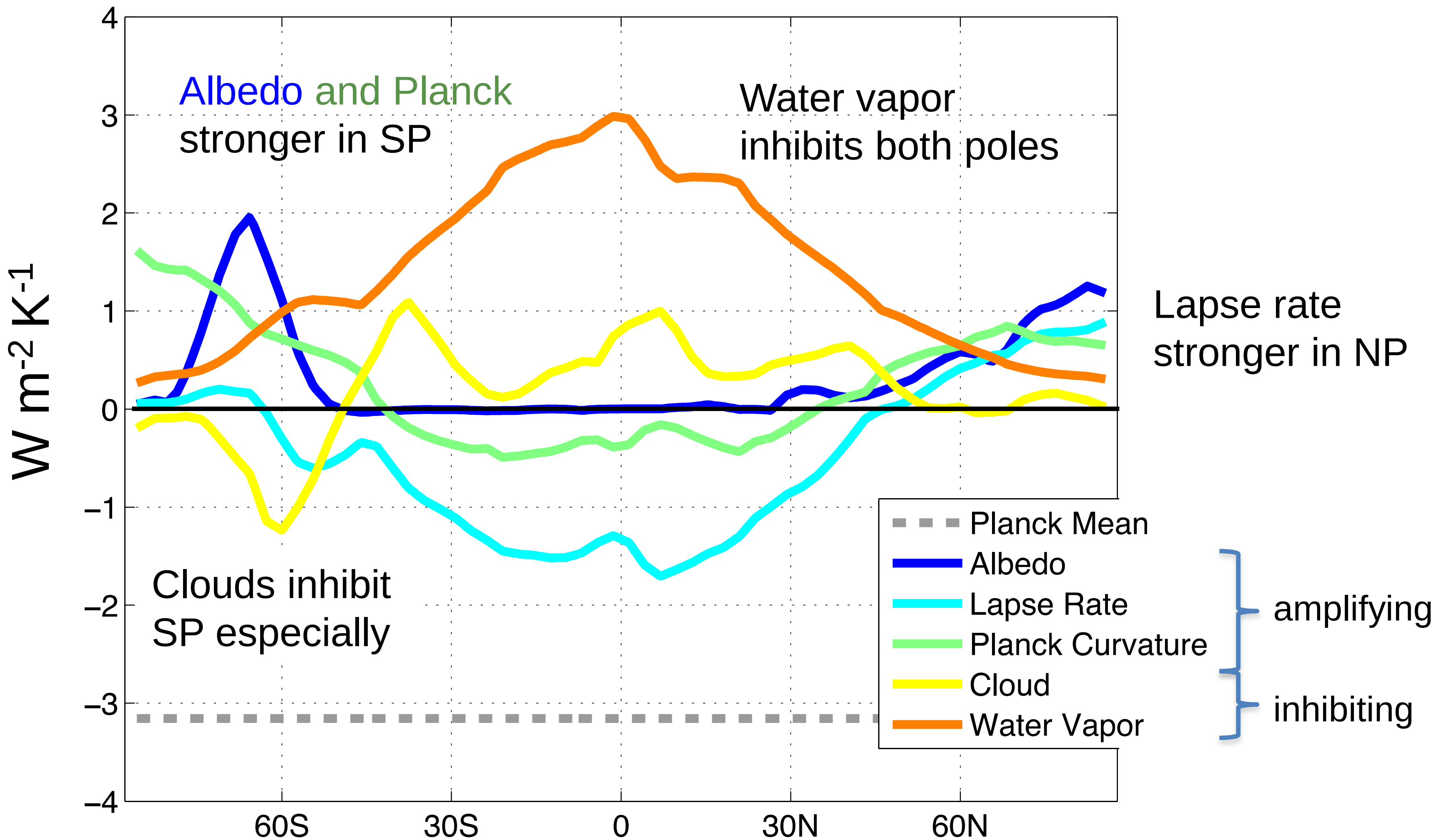




4XCO2 warming relative to surface in CMIP5 models

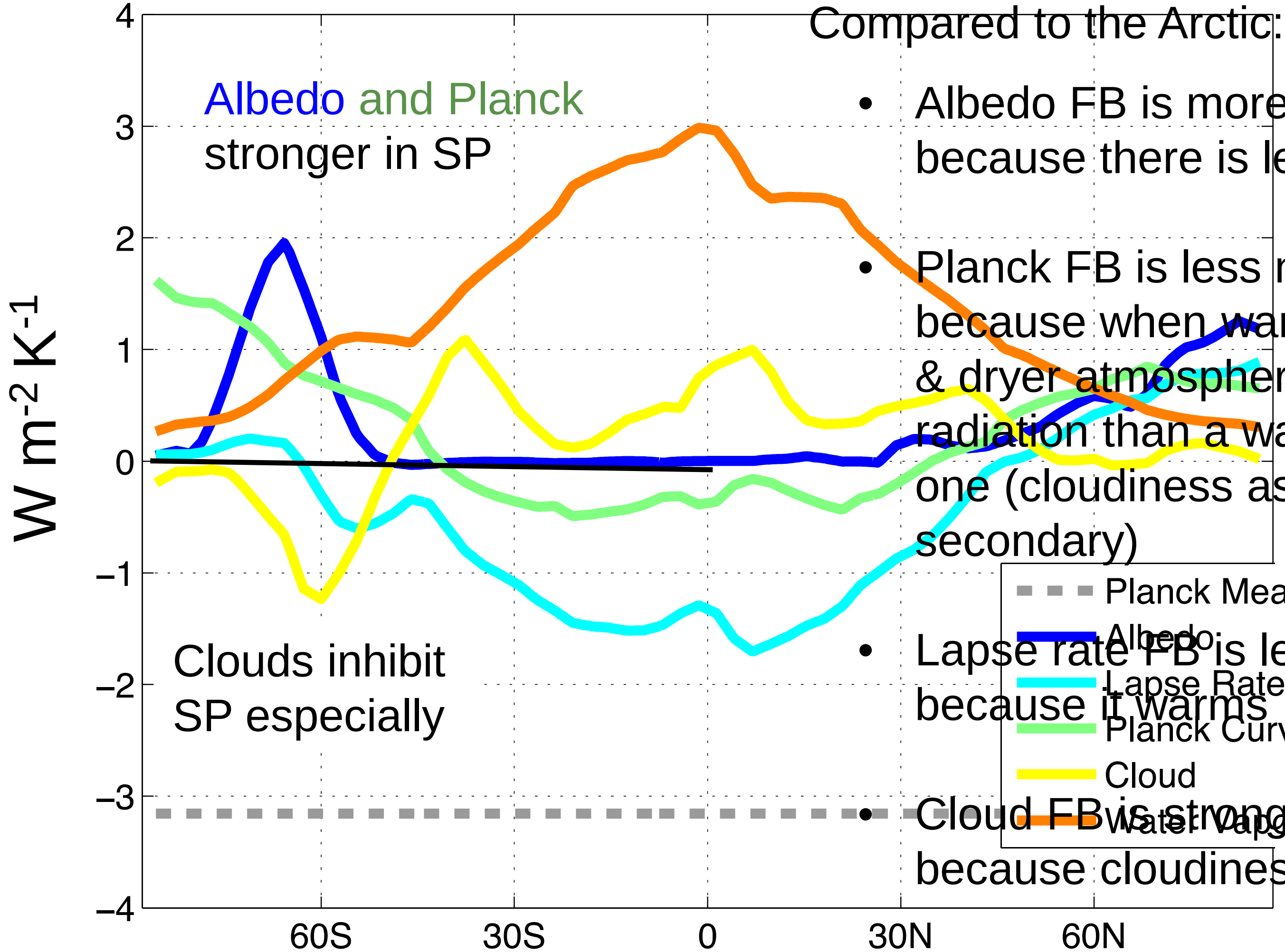
Note polar asymmetry too

Feedbacks and Their Contribution to Polar Amplification



Computed for abrupt 4XCO2 CMIP5 after 140 yrs relative to Pre Industrial (normalized by “local” zonal-mean warming)

Feedbacks and Their Contribution to Polar Amplification



Compared to the Arctic:

- Albedo FB is more positive because there is less cloud cover
- Planck FB is less negative because when warmed, a colder & dryer atmosphere emits less radiation than a warmer & moister one (cloudiness asymmetry is secondary)
- Lapse rate FB is less positive because it warms less at the surf.
- Cloud FB is strongly negative because cloudiness increases

Also see Taylor et al (2013)

Planck Feedback

$$\lambda p = \int_{p_o}^{p_s} K_T(x,y,p)\overline{T}(x,y)dp + K_{Ts}(x,y)T_s(x,y)$$

atm. term surf. term

Lapse Rate Feedback

$$\lambda_{LR} = \int_{p_o}^{p_s} K_T[T(x,y,p) - T_s(x,y)]dp$$

K_T and K_{Ts} are the change in OLR from perturbing T by 1K at every point

Temperature Kernel – CAM Model

K_T

Less negative at South Pole

(polar asym. is in clear sky too)

0.16 -0.14 -0.12 -0.1 -0.08 -0.06 -0.04 -0.02 0

W m^{-2} K^{-1} hpa^{-1}

For Planck FB, $K_T(x,y,p)$ is multiplied by a positive number, so Planck FB is less negative at SP

Temperature Kernel – CAM Model

K_T

Less negative at South Pole

W m^{-2} K^{-1} hpa^{-1}

0.16 -0.14 -0.12 -0.1 -0.08 -0.06 -0.04 -0.02 0

Clear-sky ONLY also less negative at South Pole, so clouds are not key to asymmetry above

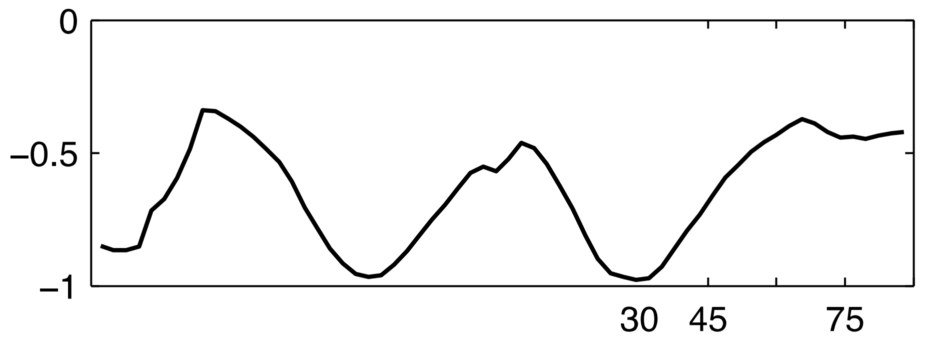
Temperature Kernel – CAM Model

K_T

Less negative at South Pole

K_{Ts}

More negative at South Pole



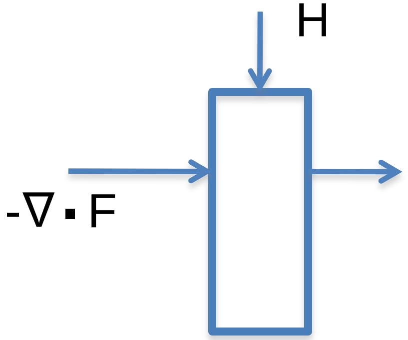
But Planck FB surface term is small, so it does not dominate the overall Planck FB polar asymetry

TOA flux balance response = global radiative response + radiative forcing + residual

(each term is a response to forcing, not showing Δ for change)

$$H = \lambda T + R_f + r$$

H = TOA flux balance response OR convergence of heat transport in atmosphere & ocean



Atm & Ocn Column

TOA flux balance response = global radiative response + radiative forcing + residual

$$H_{atm} + H_{ocn} = (\overline{\lambda_P} + \lambda_p' + \lambda_{others})T + R_f + r$$

(suppressing Δ symbols)

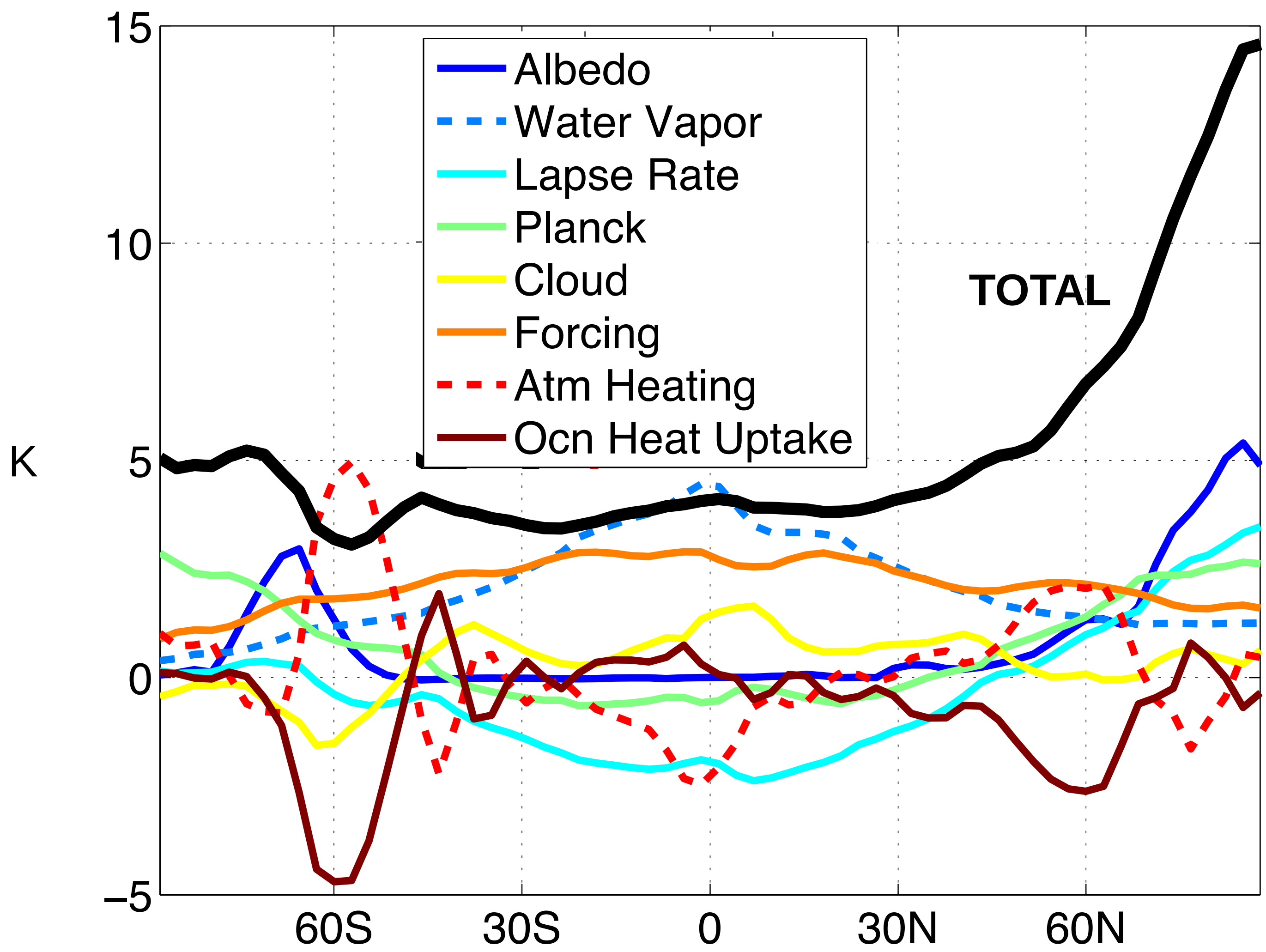
Divide by λ_p and solve for T:

$$T = \overline{\lambda_P}^{-1}[H_{atm} + H_{ocn} - (\lambda_p' + \lambda_{others})T - R_f - r]$$

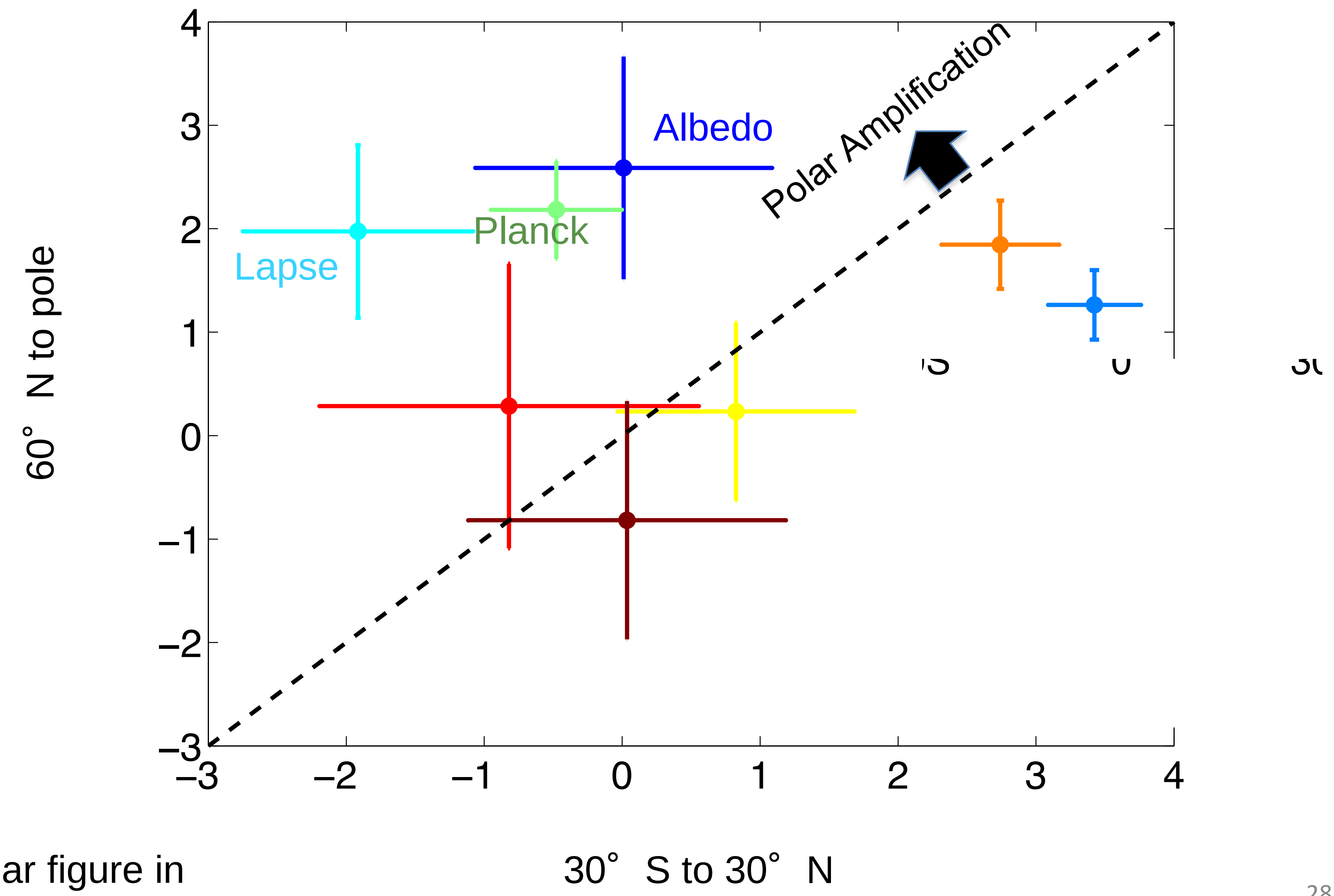
Each term gives a "Warming Contribution"

Concept of Feldl & Roe (2013)
and Pithan & Muaritsen (2014)

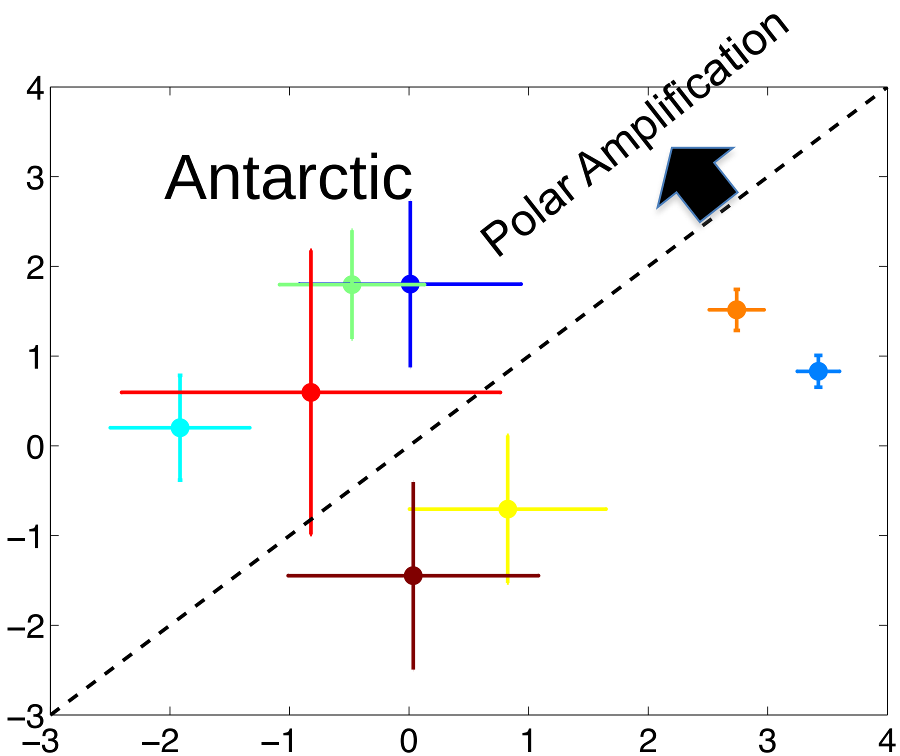
Warming Contributions in Response to 4XCO2 in CMIP5 Models

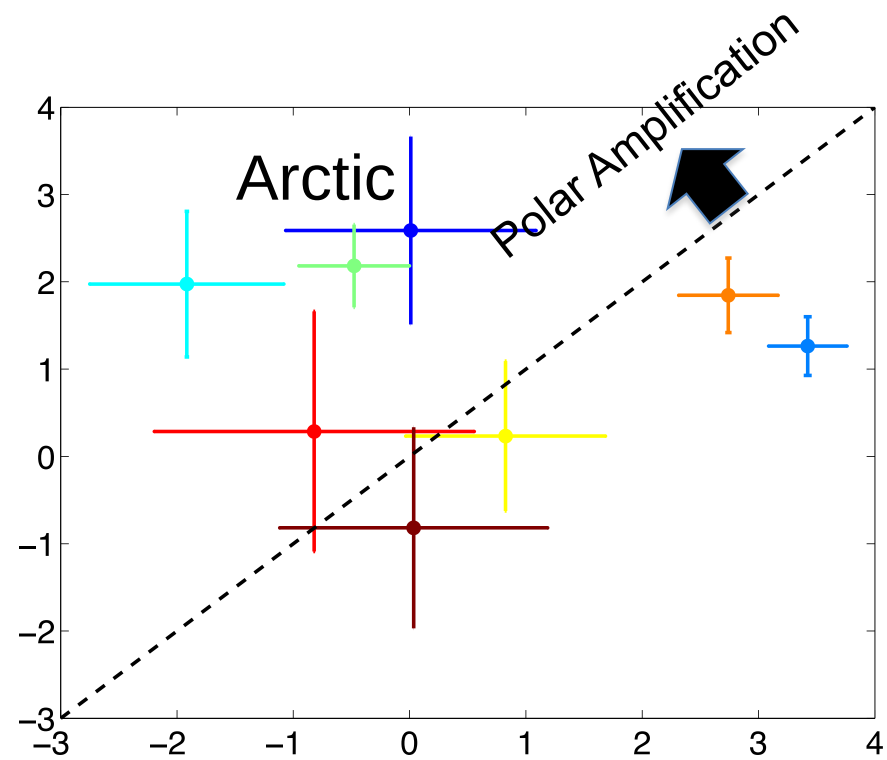


Arctic Warming Contributions in Response to 4XCO



Similar figure in
Pithan & Muaritsen (2014)





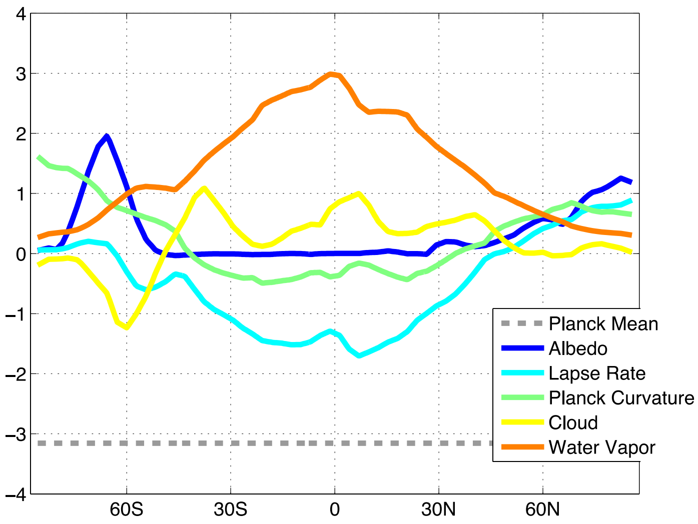
Recast in this way, contributions from lapse rate and albedo FB are smaller than in the Antarctic

Ocean heat uptake, water vapor FB, and the radiative forcing are more inhibiting

Atmospheric heat transport picks up some of the slack

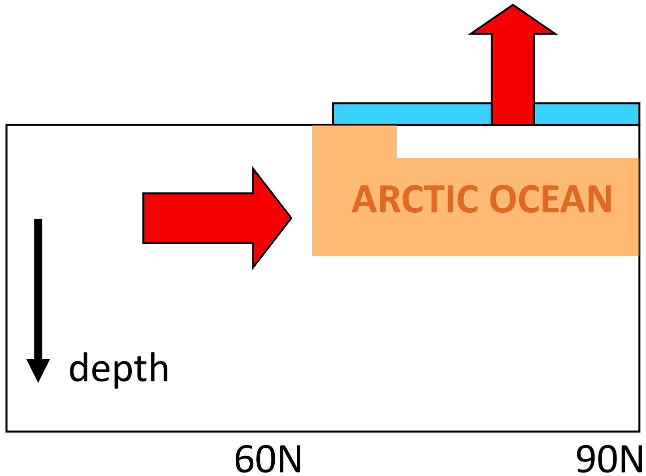
Summary

CMIP5 models indicate that total radiative feedback in the Antarctic is smaller than in the Arctic owing to the colder and dryer atmosphere and the greater increase in clouds over the Southern Ocean. Albedo FB is the exception, it is larger in the Antarctic. But in neither hemisphere is albedo FB as dominate as was previous thought (by me at least).



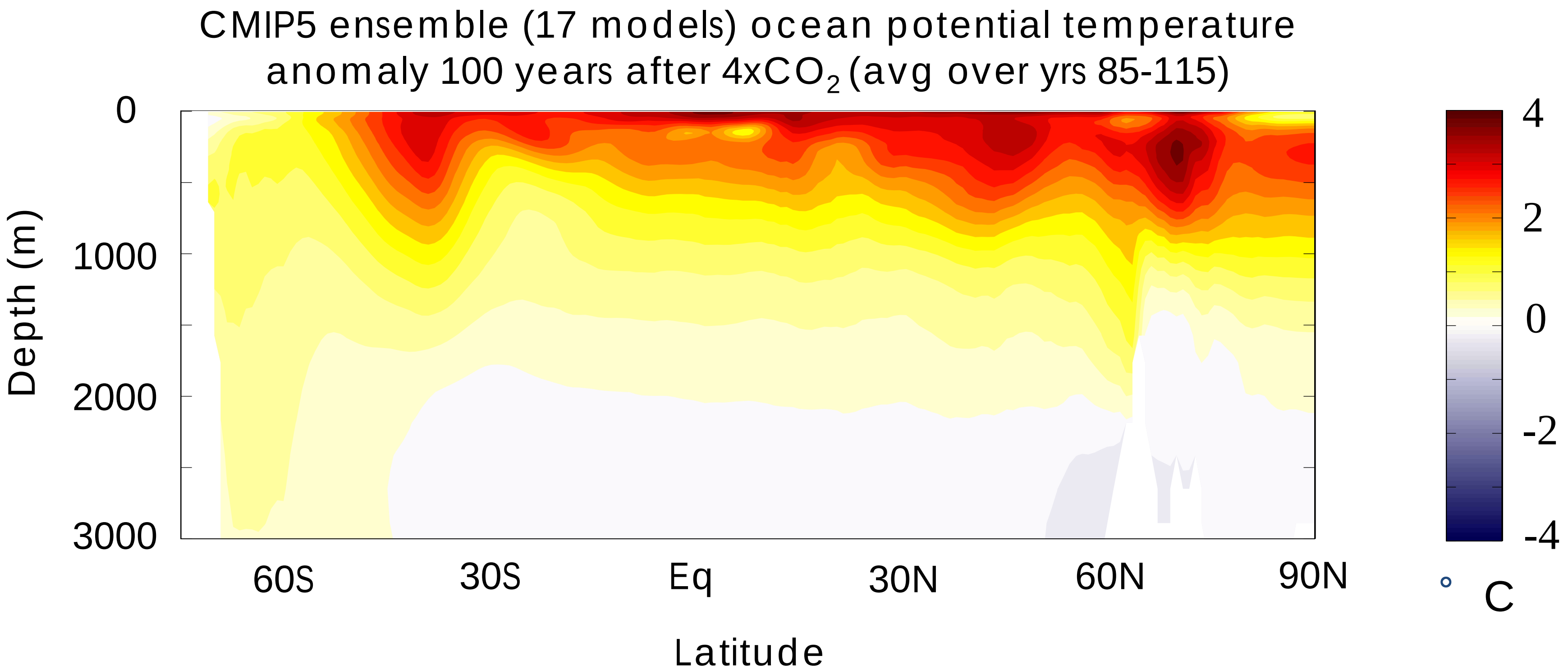
The radiative forcing from CO_2 is weaker in the Antarctic.

Ocean heat uptake is larger in the Antarctic owing to large-scale upwelling, buffering change at the surface. In contrast, the Arctic experiences an increase in horizontal oceanic heat transport, so that the ocean looses more heat to the atmosphere (more than compensating increased shortwave absorption).



Atmospheric heat transport compensates, but incompletely.

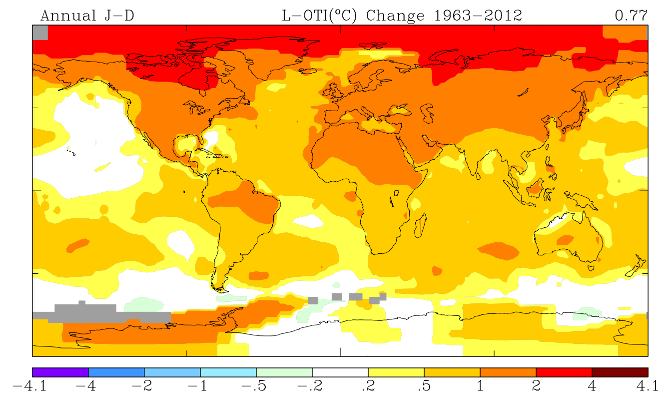
Where does ocean heat uptake go?



From Kyle Armour

Summary

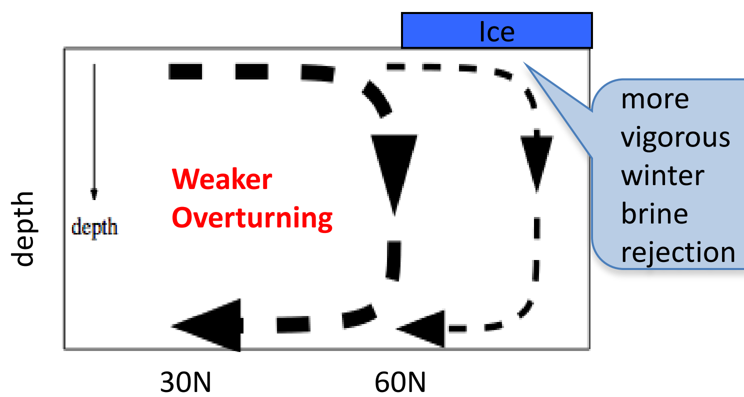
Polar amplification is the greater rate of surface temperature change at the pole than the globe under forcing. It is a characteristic of the climate system. The signature of it can be delayed by ocean heat uptake. It can take time to “emerge” from natural variability.



Mechanism and seasonality

- Thinning sea ice enhances it most in fall
- Lapse rate and Planck feedbacks area at least as important as albedo
- Ocean heat transport probably enhances Arctic Amp. most in fall and winter
- Remote SST warming causes Arctic warming aloft, via latent heat advection

Prevalent in climate models with large spread, much of spread can be explained by ocean heat uptake and atmospheric heat transport.



Summary

Why do models disagree with observations in the Antarctic?

Some possibilities:

- Model biases (clouds and ocean mixing)
- Ozone depletion (do CMIP models transition to the fast response to soon?)
- Lack of freshwater melting increase from base of shelves
- Lack of correct tropical teleconnections