The impact of stratospheric ozone chemistry on climate sensitivity

Gabriel Chiodo

Lorenzo Polvani

Columbia University, New York

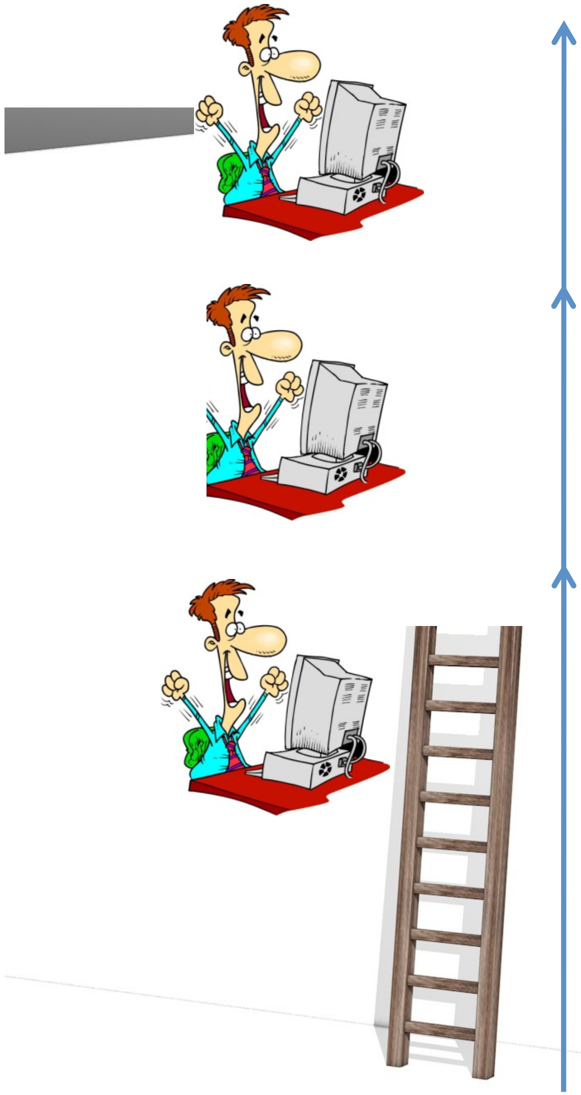
Princeton University, 11/04/2016

COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

WACCM

Climbing up the model's ladder



Coupled chemistry climate models (CCMs – CCMI initiative)

FV 2 deg: 1700 cpuh/model yr

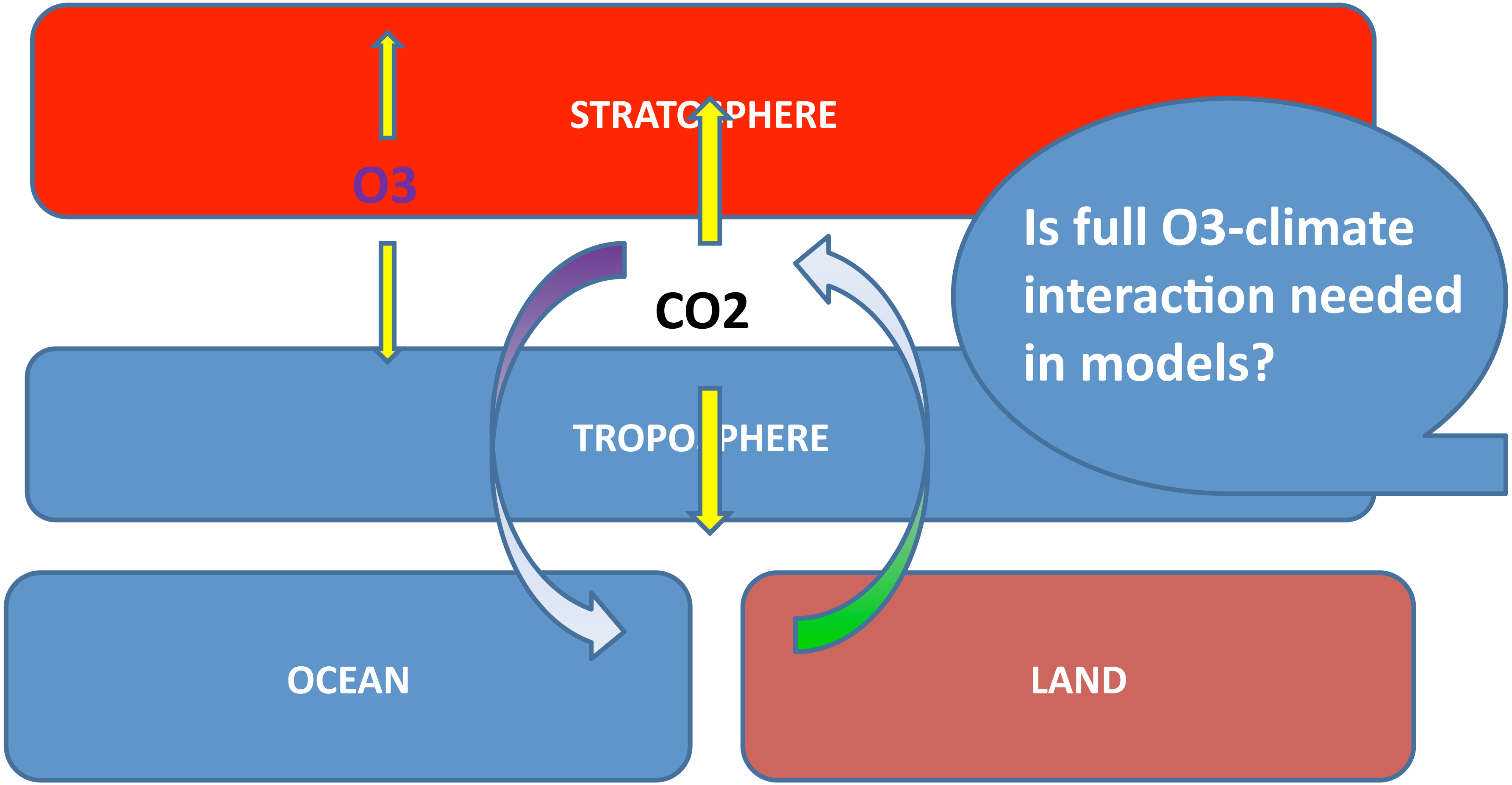
High top AO-GCMs (CMIP5)

FV 2 deg: 700 cpuh/model yr

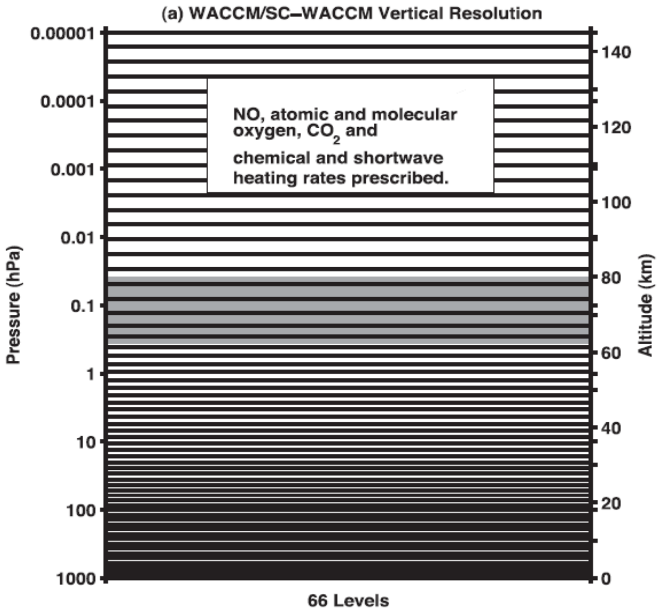
Complexity ladder

Do ozone chemistry feedbacks matter?

$$\frac{dTs}{dCO_2} = .$$



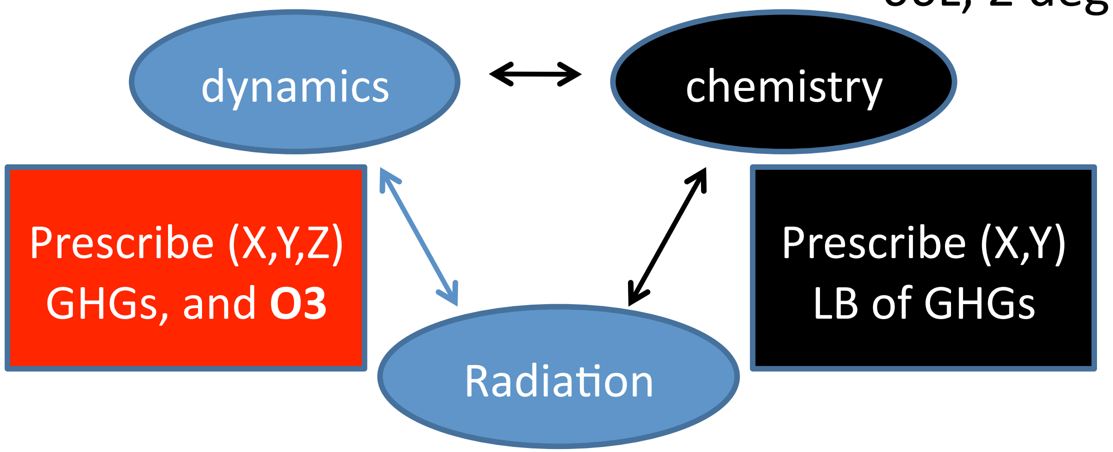
A unique tool to quantify ozone feedbacks: WACCM vs SC-WACCM



The Whole Atmosphere Community Climate Model v4 (Marsh et al., 2014) is a high-top GCM, which can be run with:

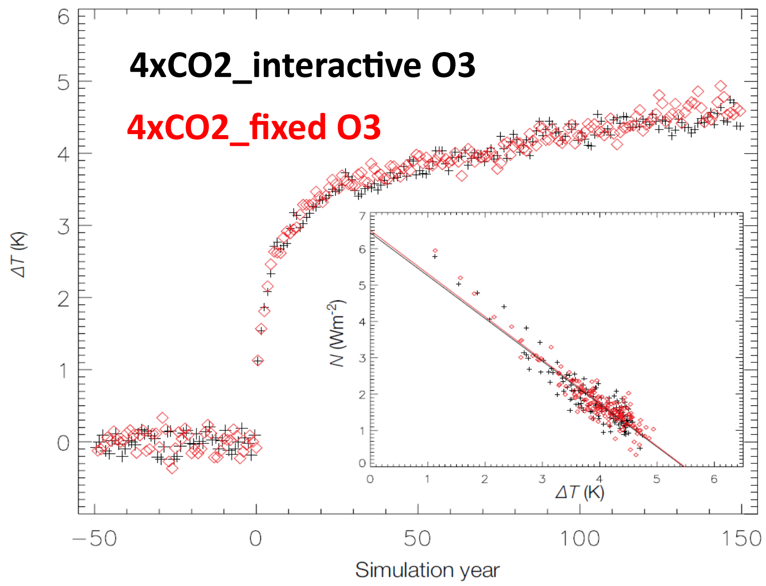
-**Fixed ozone climatology** (**SC-WACCM**)
66L, 2 deg FV, POP2 ocean

-**Interactive ozone** (**WACCM**)
Advection and photochemistry of 60+ species
66L, 2 deg FV, POP2 ocean



....MORE DETAILS IN SMITH ET AL,14

- Impact of ozone chemistry on ECS in WACCM



O3 effect = 0 %

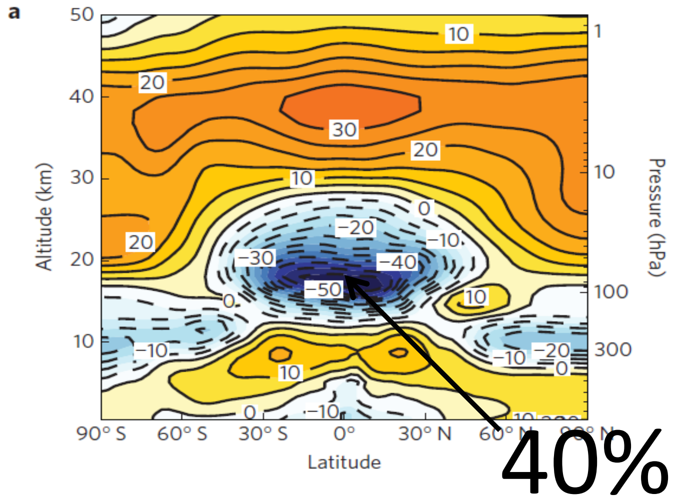
Marsh et al. GRL 2016

- Impact on ECS in other models:

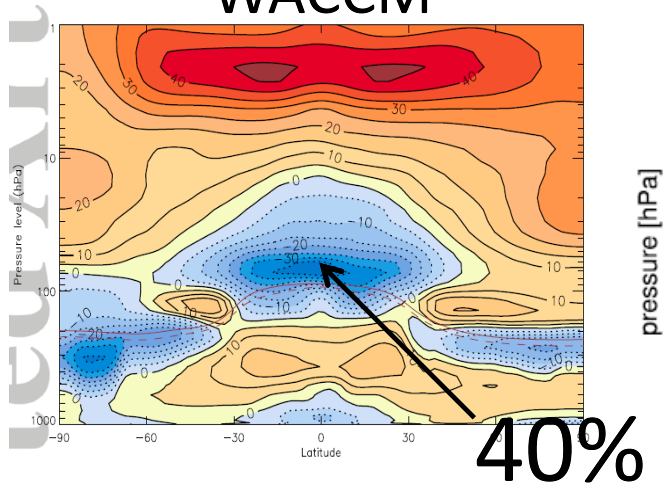
HADGEM	ECHAM-MESSY	SOCOL
4xCO2_intO3 = 4.8 K	4xCO2_intO3 = 7.5 K	4xCO2_intO3 = 7.5 K
4xCO2_fixO3 = 5.9 K	4xCO2_fixO3 = 8.1 K	4xCO2_fixO3 = 8.0 K
O3 effect = -20 %	**O3 effect = -8 %**	**O3 effect = -8 %**
Nowack et al. NCC 2014	*Diemuller et al., 2014*	*Muthers et al., 2014*

Ozone response to 4xCO2: **robust!**

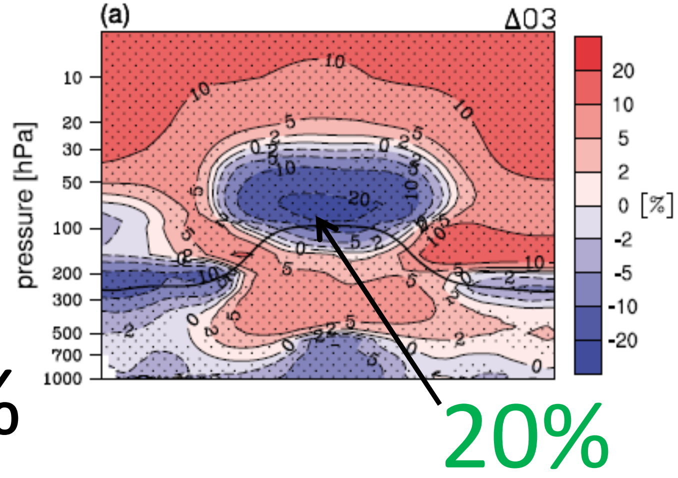
HADGEM



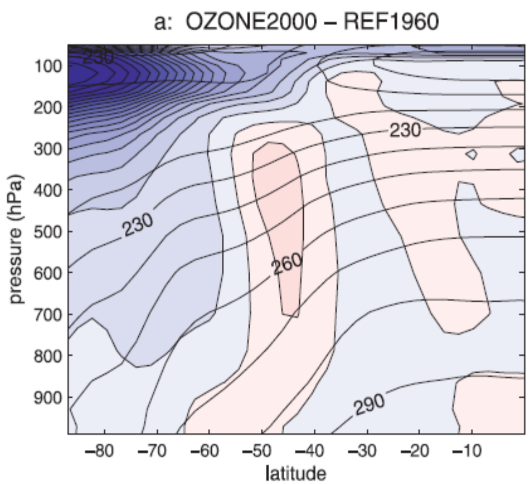
WACCM

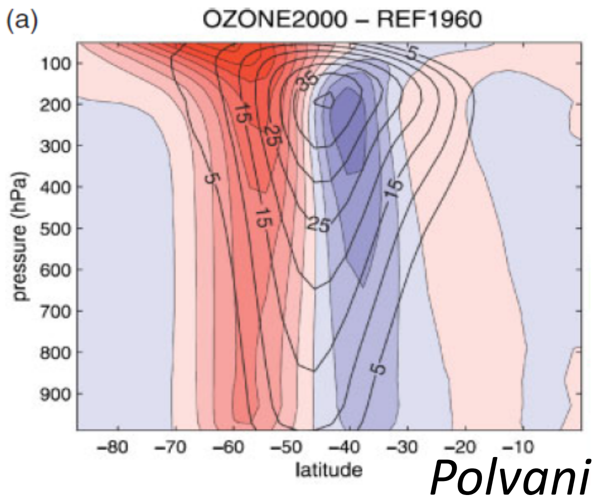


ECHAM-MESSY (2xCO2)



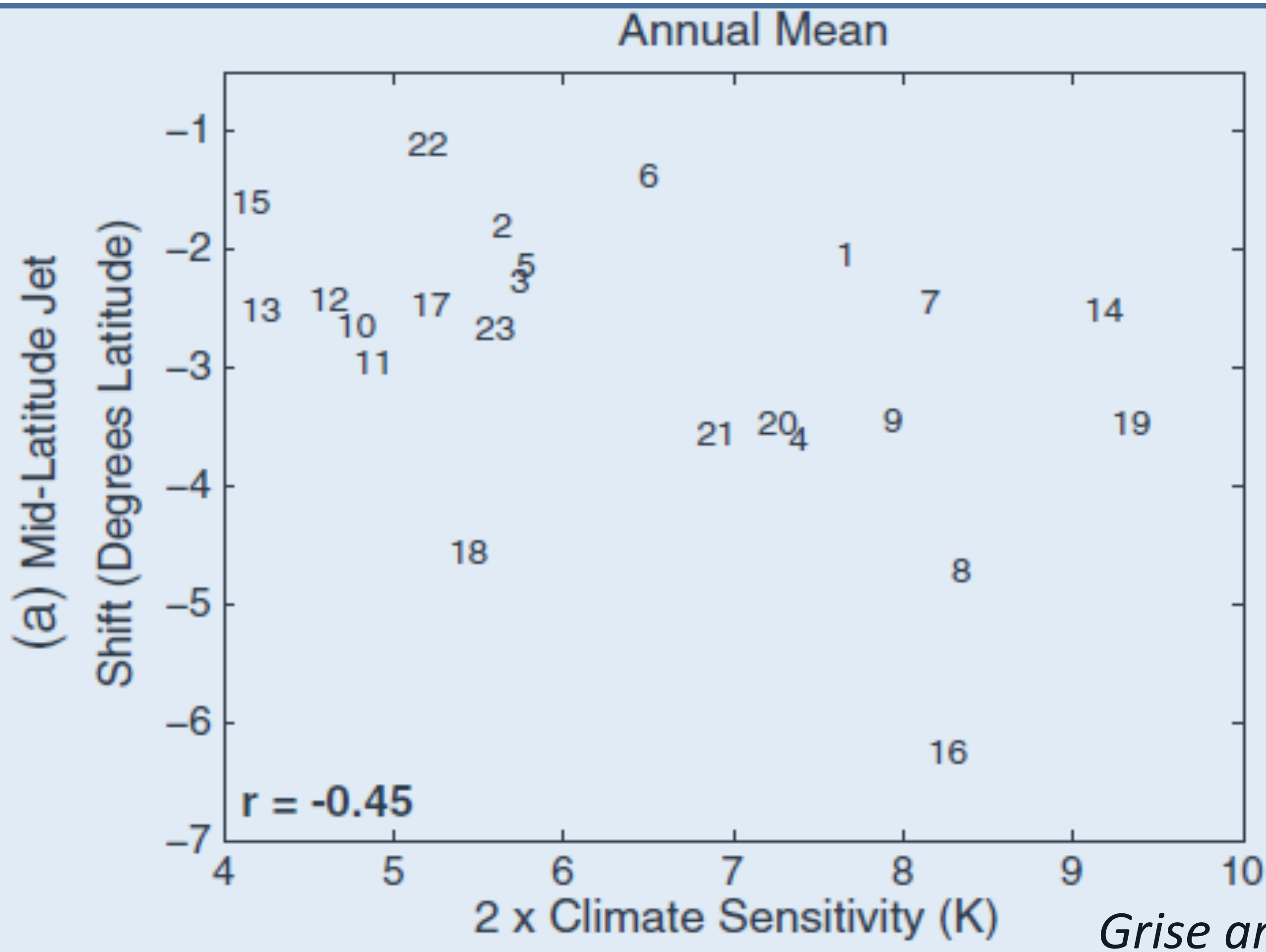
O3 changes (depletion/recovery) have a large effect on tropospheric circulation…





Polvani et al., 2011

Is the stratospheric ozone feedback crucial for the **dynamical** sensitivity (SH extratropical circ. response)?



Grise and Polvani GRL 2014

Aim of this work

- Quantify the model response to 4xCO_2 in WACCM, without any changes in CFCs. Hence, we quantify CO_2-driven **O_3 feedback**!

- **Examine whether stratospheric ozone chemistry feedbacks alter the SH circulation response to 4xCO_2**

Model-set up

WACCM
(interactive)

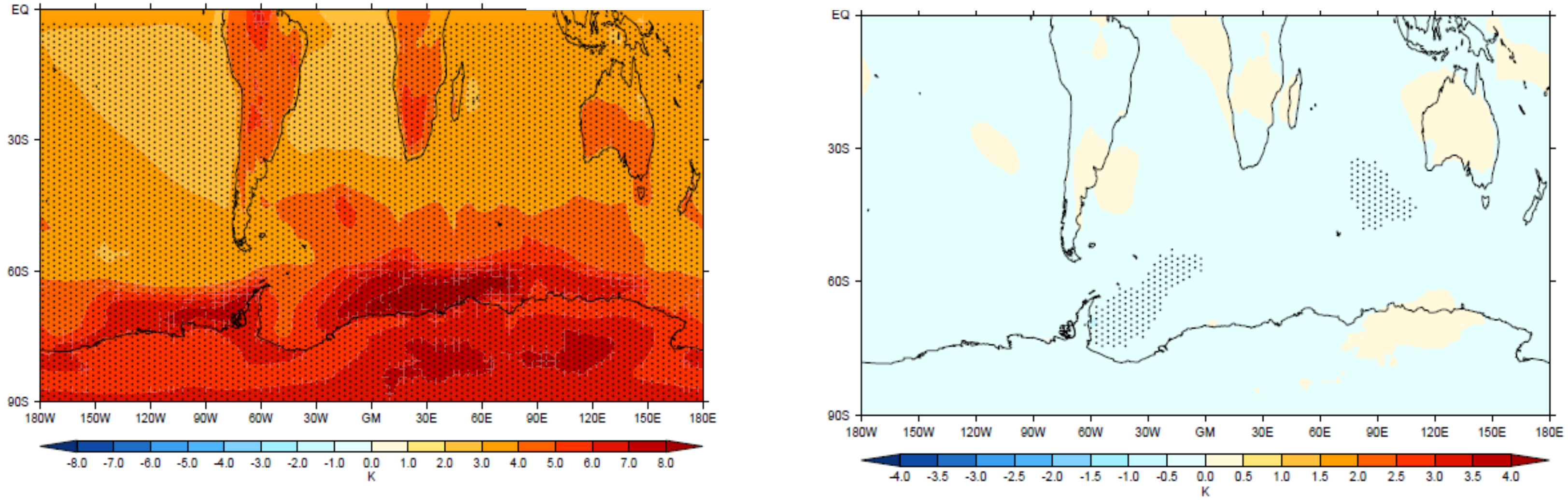
- **ctrl_interactiveO3 (200 y)**
- **4xCO2_interactiveO3 (200 y)**

SC-WACCM
(no chemistry, i.e. no ozone feedback)

- **ctrl _fixedO3 (200 y)**
- **4xCO2_fixedO3 (200 y)**

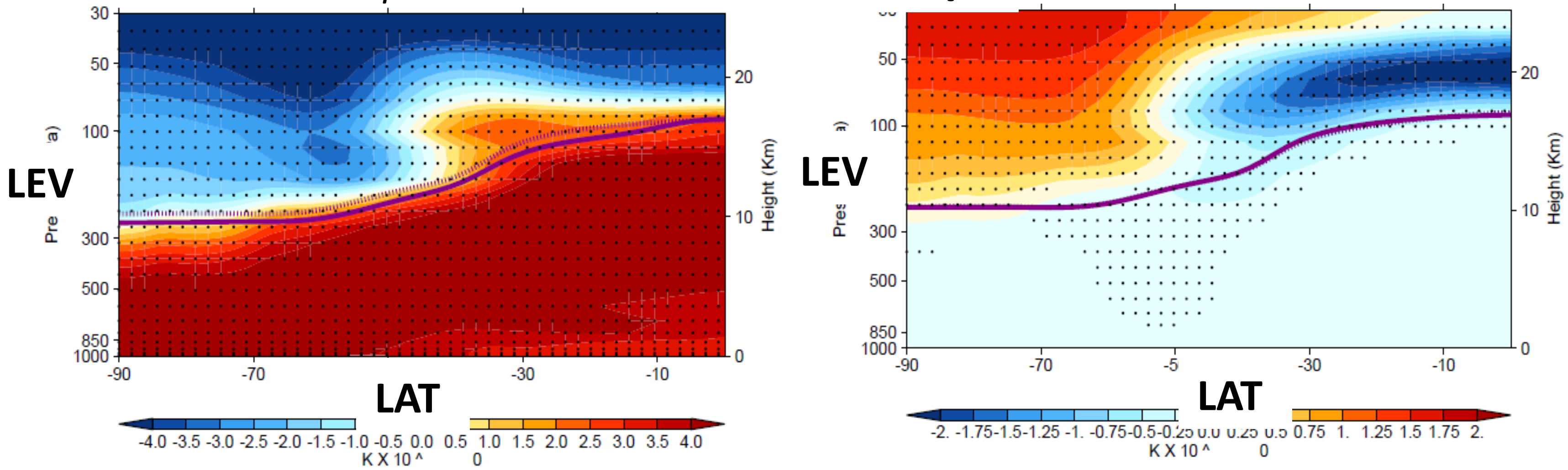
Chiodo and Polvani, 2016 (GRL, under review)

4xCO2 response **Surf. Temperature** *change due to interactive O3*



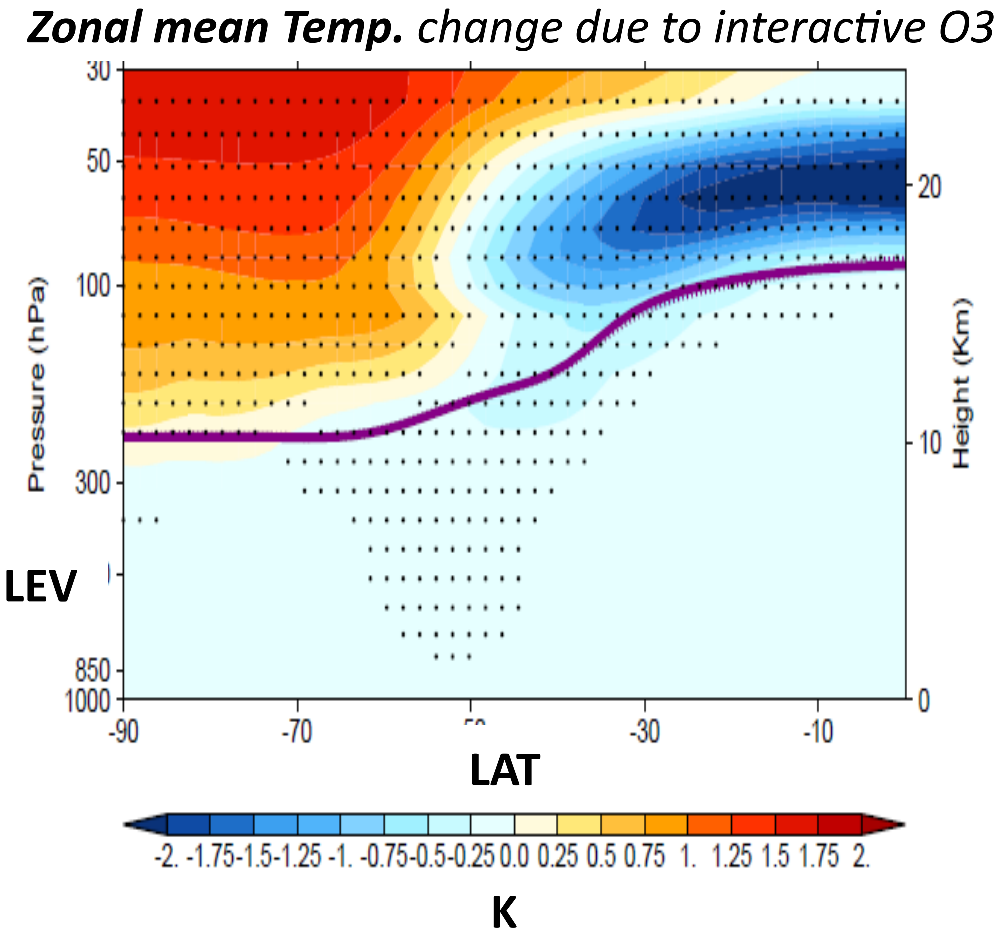
- **No effect** of stratospheric ozone chemistry on **surface response**

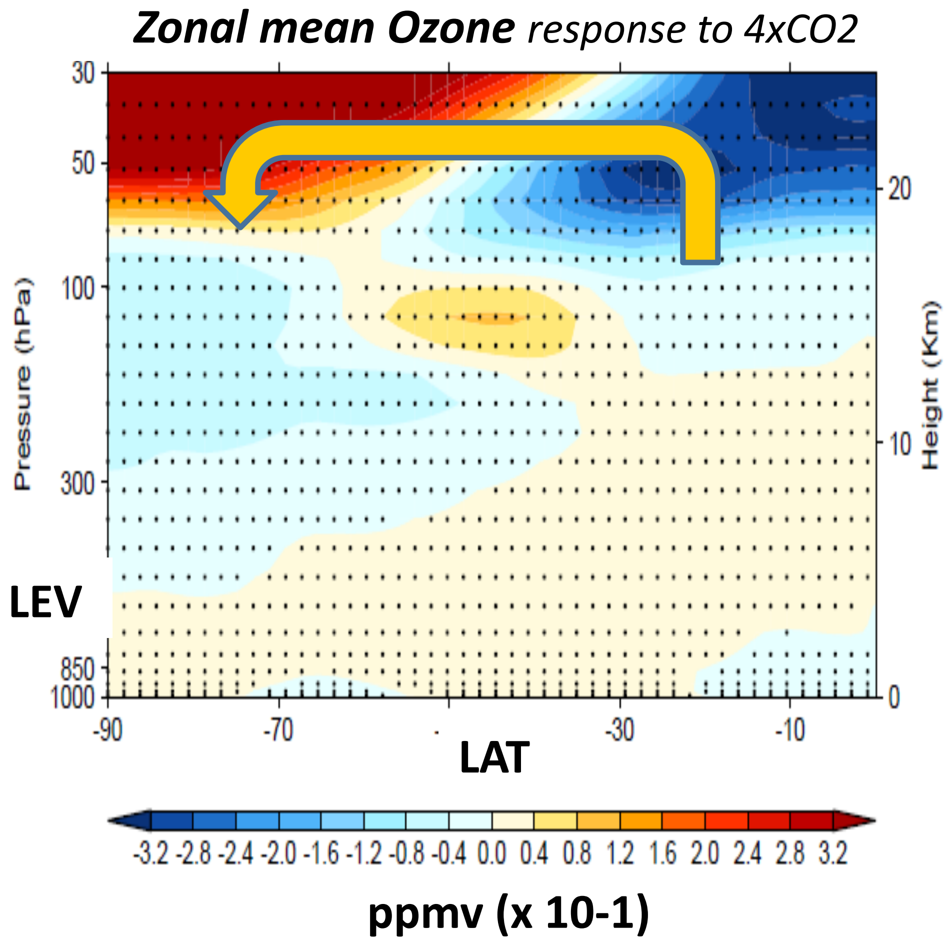
4xCO2 response **Zonal mean Temp.** *change due to interactive O3*



- Yet, effect in lower **stratosphere** very **significant** (50 % of CO2 signal)

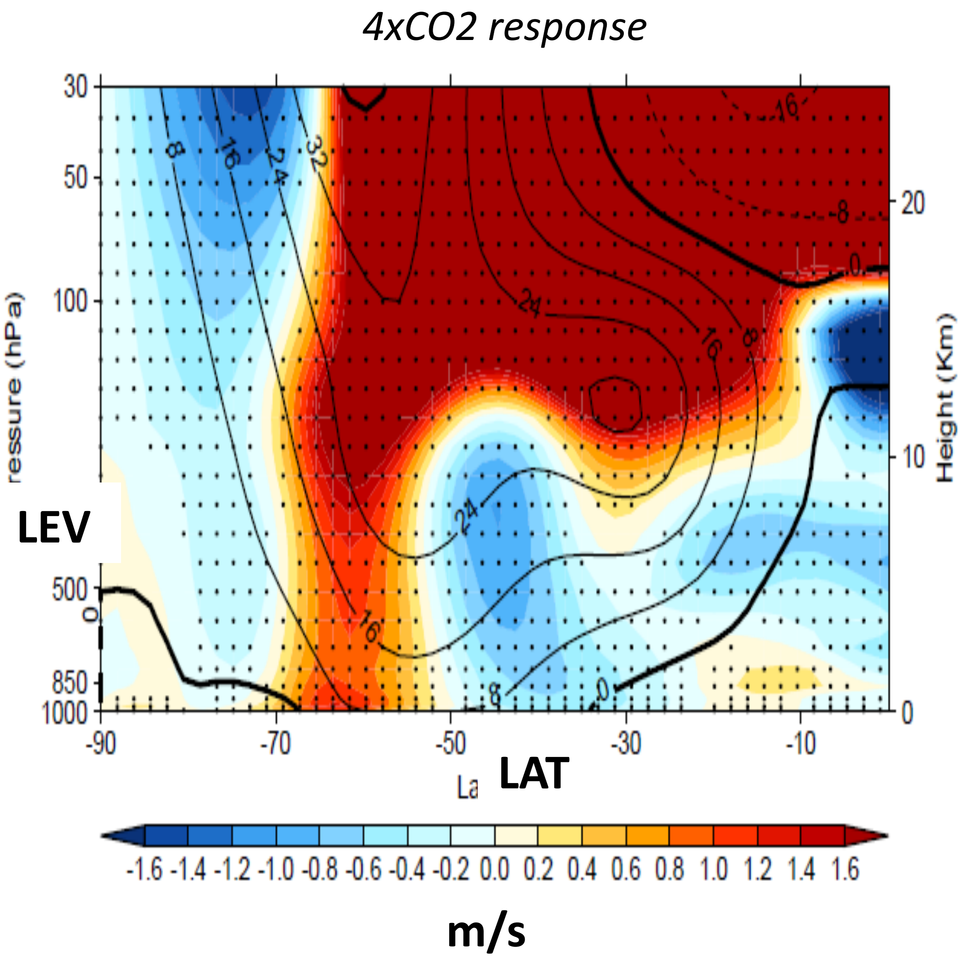
Temperature-ozone link

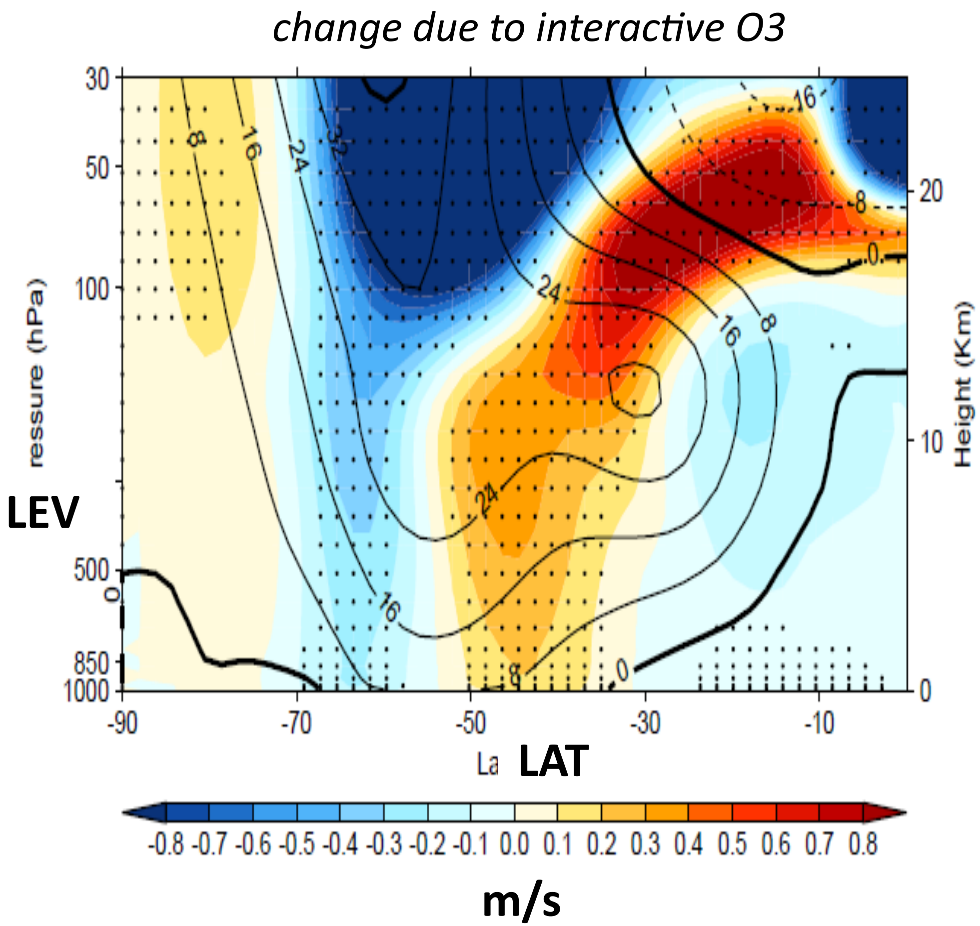




- Change in temperature **gradient** caused by **ozone response to CO2**

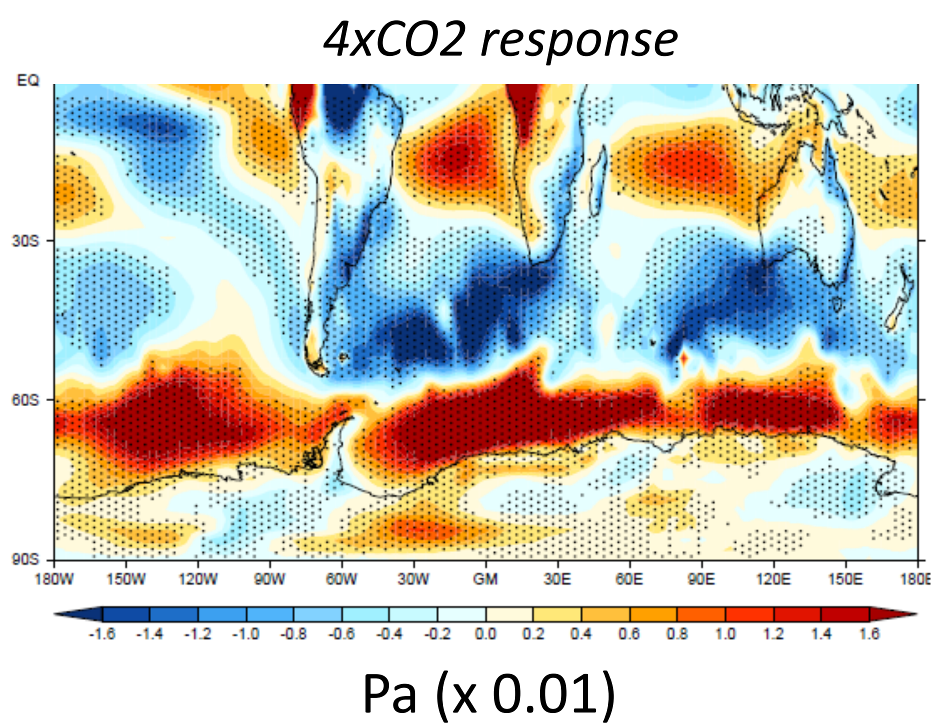
Zonal wind (annual mean)

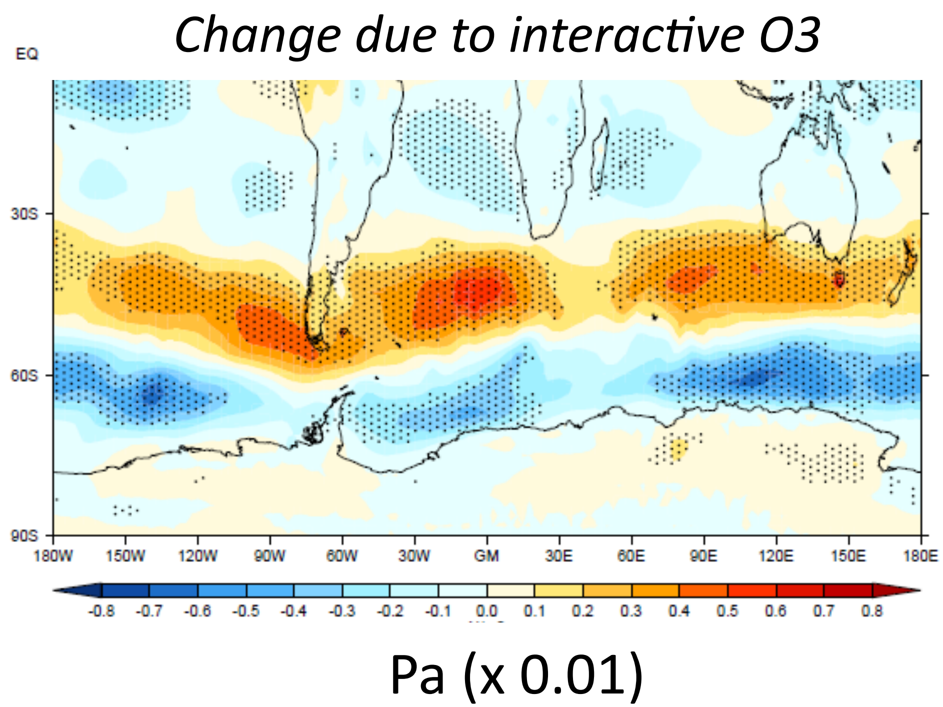




•**Response** of **eddy-driven jet** is **opposite** of that caused by **CO2**

Surface effects of ozone feedback: eastward wind stress



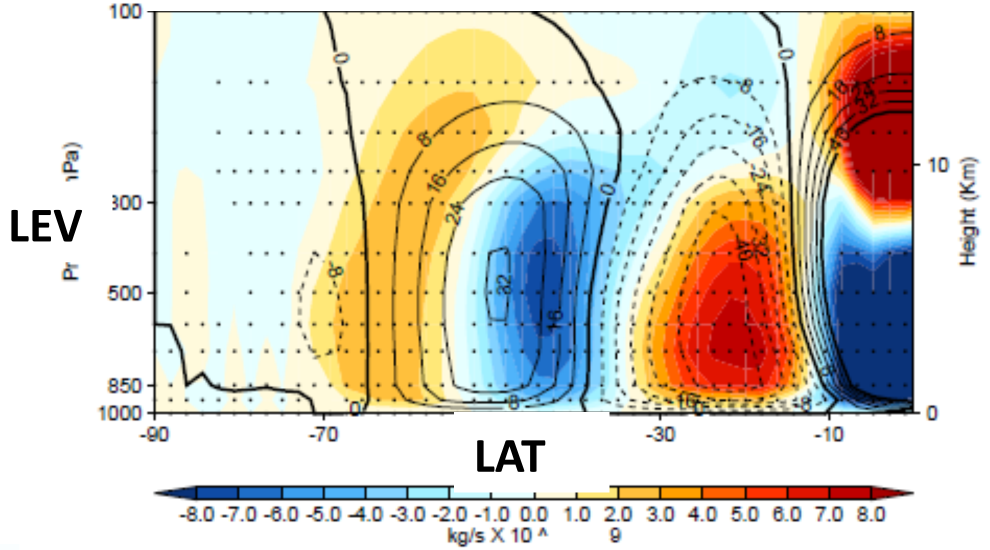


- **Interactive** stratospheric **ozone** chemistry **reduces** the **circulation response** to **CO2** by approximately 20-25 %.

- Ozone provides a **negative** feedback on **dynamical sensitivity to CO2**

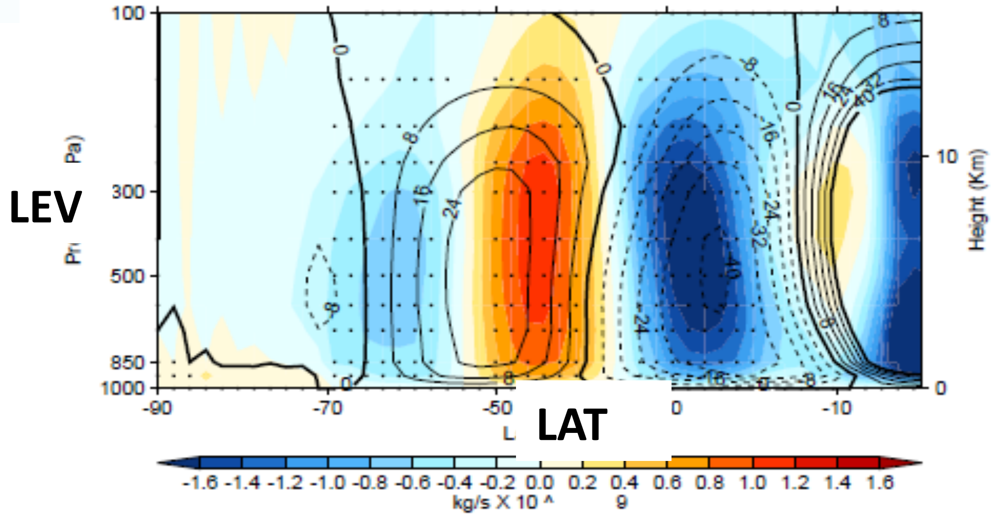
Mass streamfunction (DJF)

4xCO2 response



$$\Psi_M = \frac{2\pi a \cos\phi}{g}\int_0^p \upsilon dp$$

Change due to interactive O3



Summary and conclusions

1) The effects of stratospheric ozone chemistry on the modeled surface temperature response to CO_2 are small (and model dependent).

2) However, the response of stratospheric ozone to $4xCO_2$ is robust across models (decrease in tropics, increase over polar cap).

3) The stratospheric ozone response to $4xCO_2$ reduces (by 20-25%) the poleward shift of the SH mid-latitude jet shift (i.e., ozone chemistry provides a **negative** dynamical **feedback**)

4) Models **without interactive ozone chemistry** (AOGCMs) might **overestimate** the SH **circulation response to** $\mathbf{CO_2}$**,** due to their missing representation of negative ozone feedback on the dynamics.

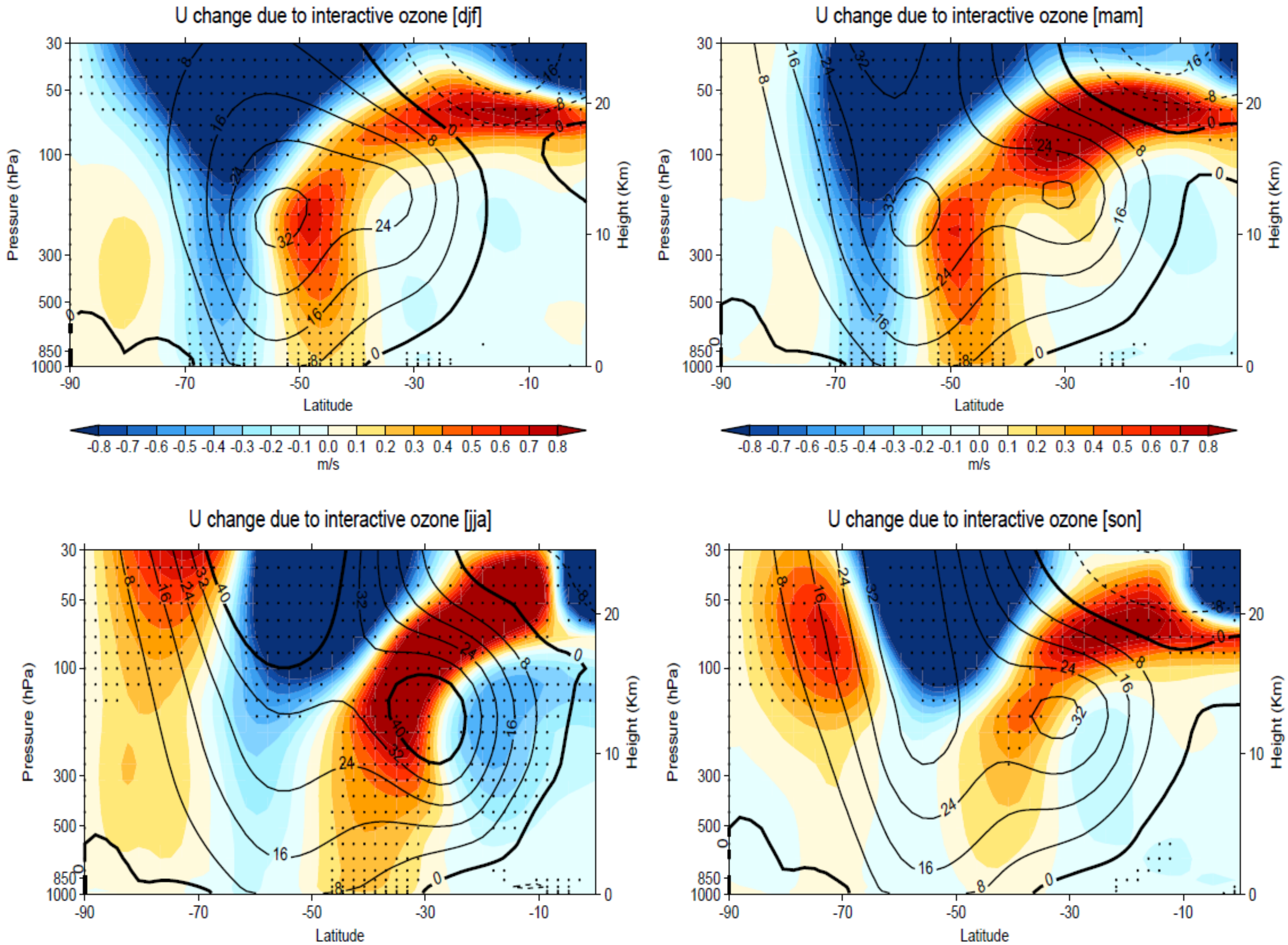
THANK YOU!

Gabriel Chiodo
chiodo@columbia.edu

Columbia Engineering
The Fu Foundation School of Engineering and Applied Science

NCAR
National Center for Atmospheric Research

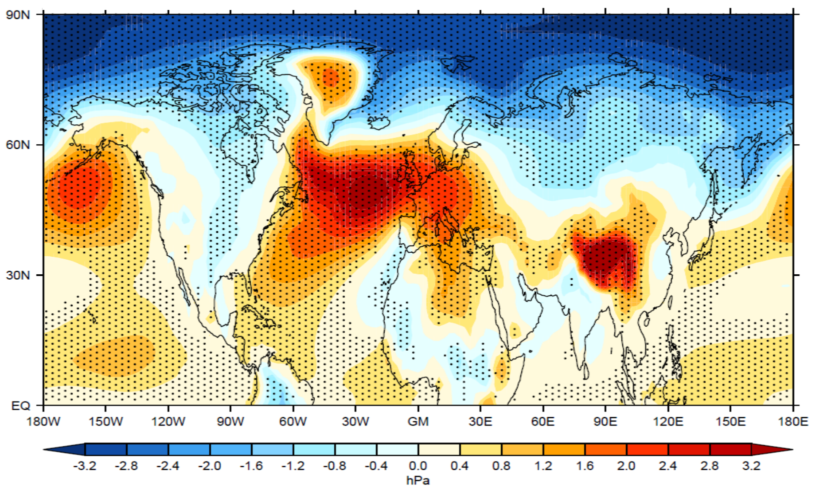
EXTRA SLIDES


U change due to interactive ozone [djf]
U change due to interactive ozone [mam]
U change due to interactive ozone [jja]
U change due to interactive ozone [son]
Pressure (hPa)
Height (Km)
Latitude
m/s
-0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

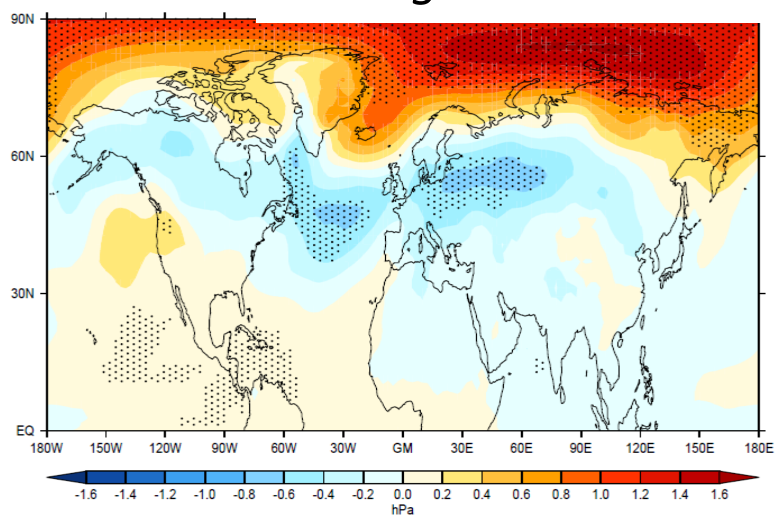
Northern Hemispheric spring (MAM)

Sea Level Pressure

4xCO2 response

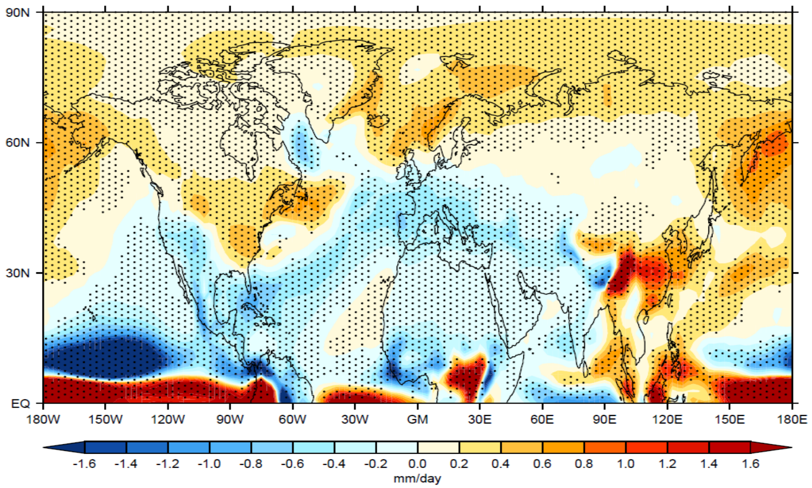


Change due to interactive O3

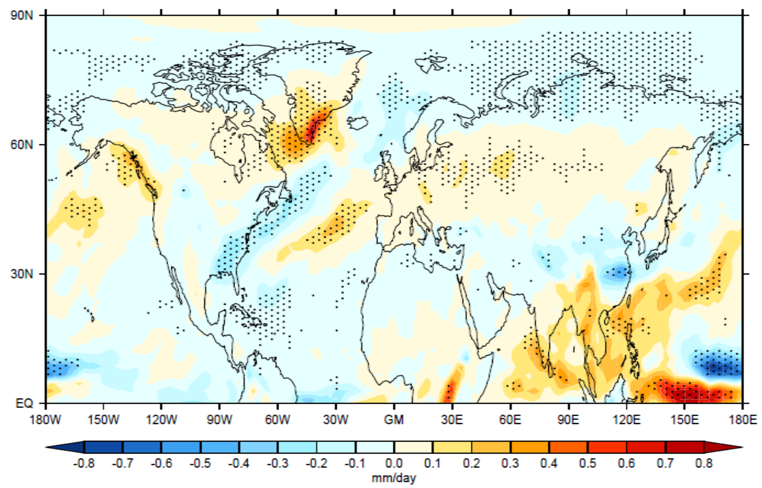


Precipitation

4xCO2 response

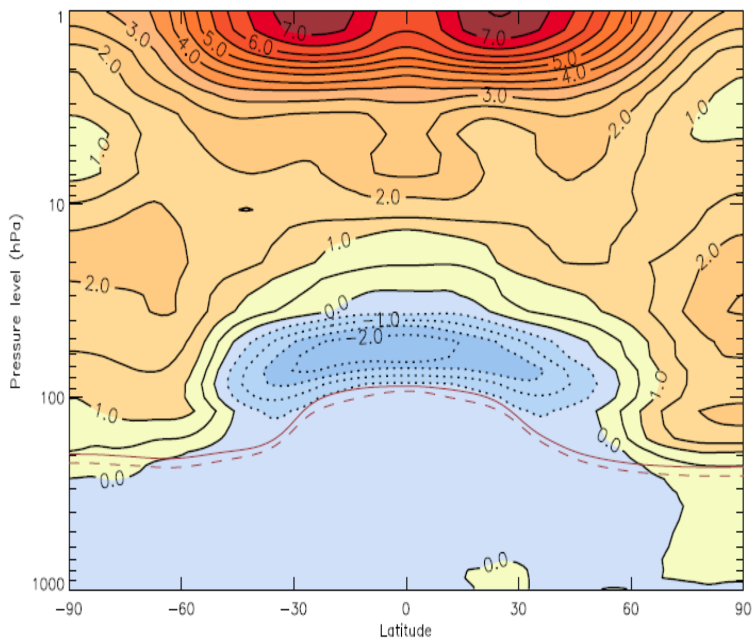


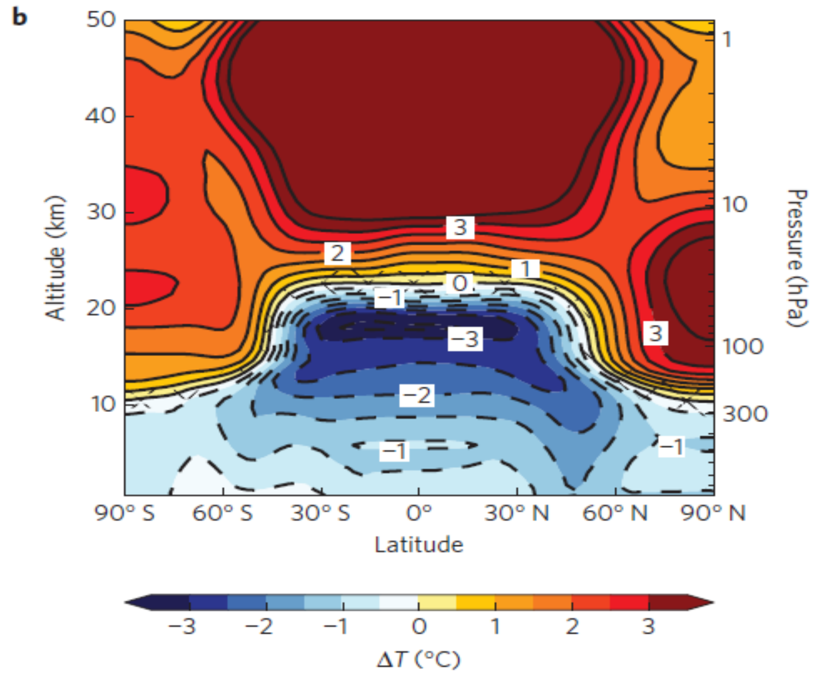
Change due to interactive O3



CAVEATS

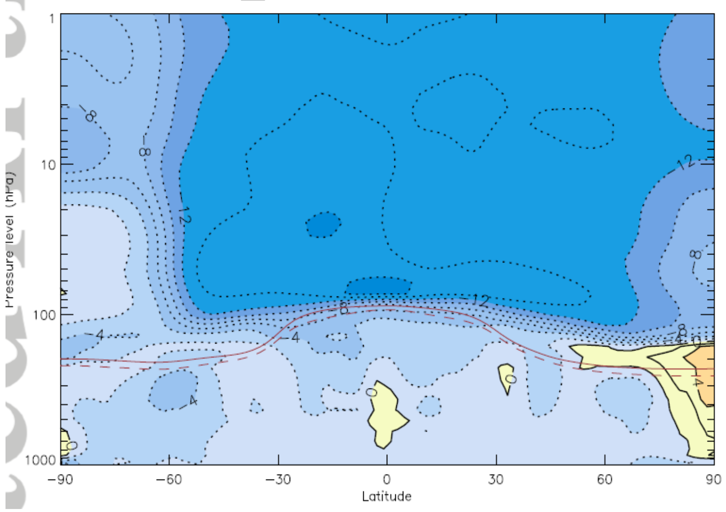
- Boundary conditions (spec. Values) for CH4 under 1850 conditions
- Methane odixation still on in SC-WACCM



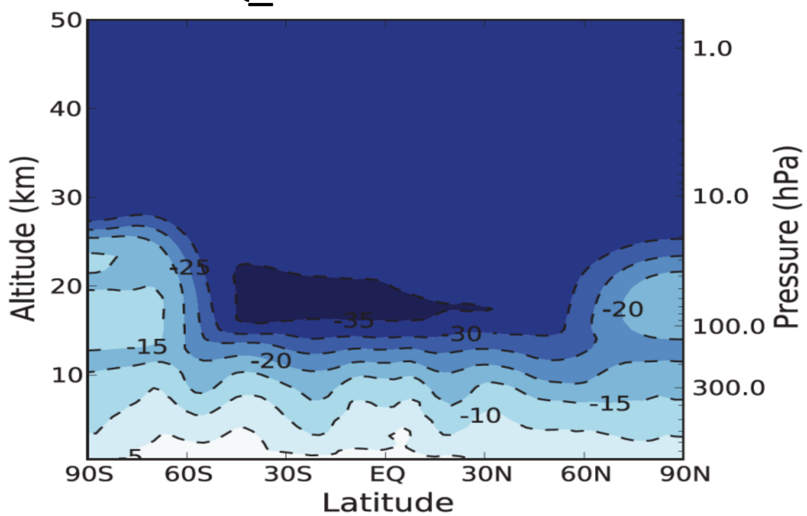


- Intermodel differences likely caused by strat.water vapour feedback

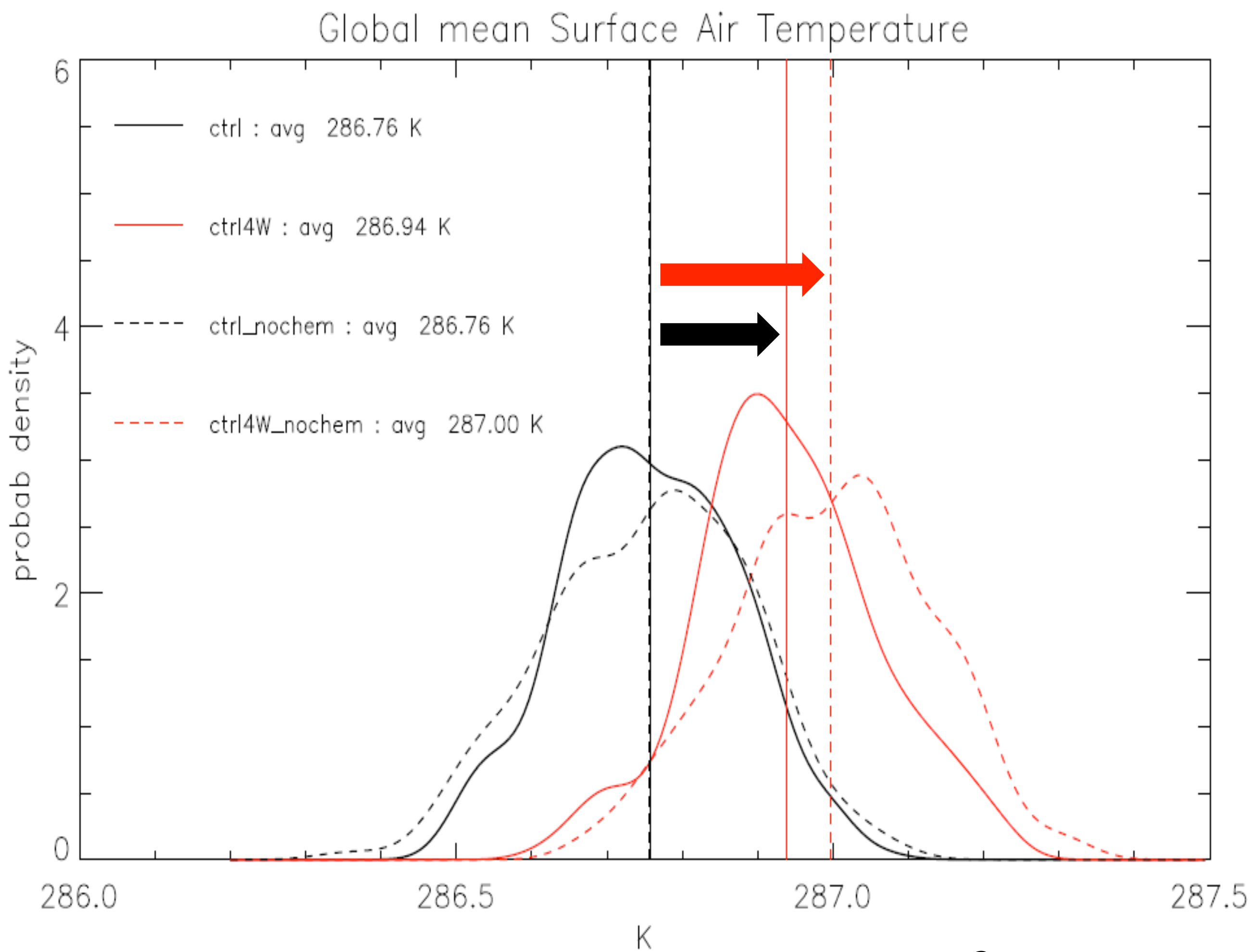
dQ_WACCM



dQ_HadGEM3



Results

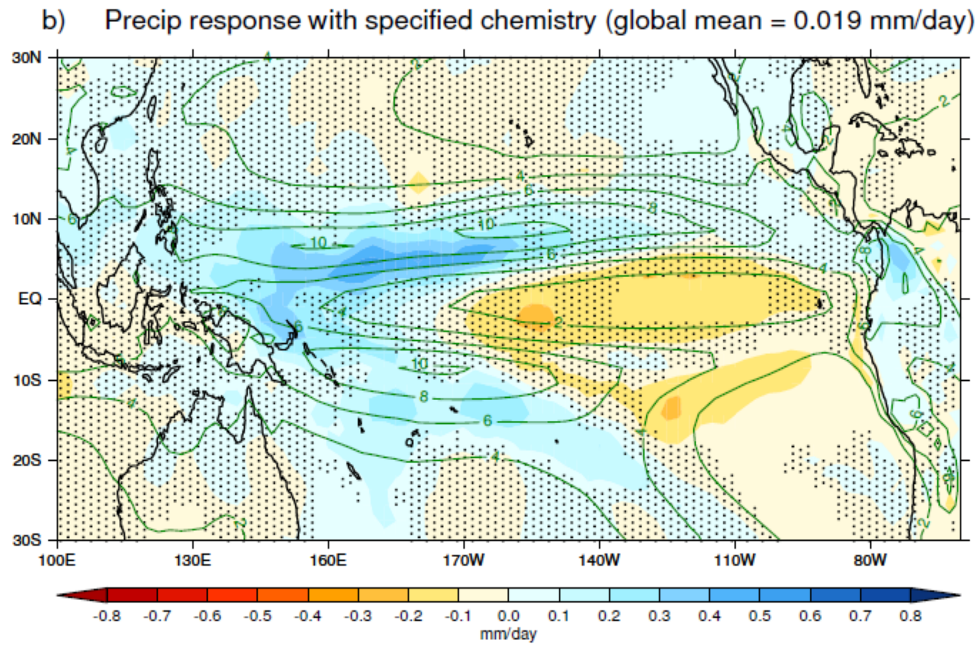


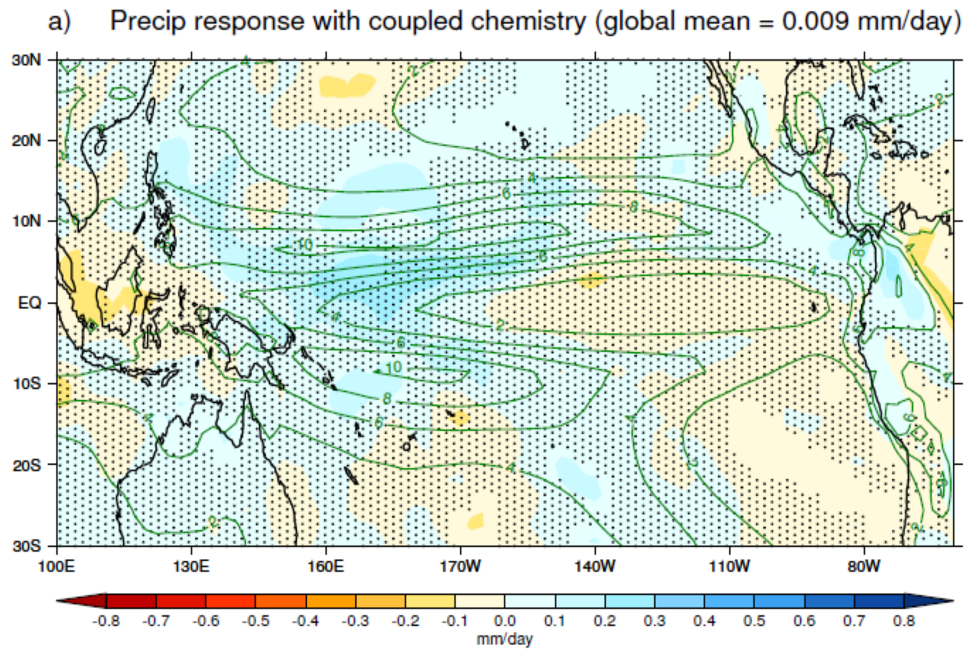
dT_chem_CO2 = 0.82 K / W / m²

dT_chem = 0.18 K
0.24 K / W / m²

dT_nochem = 0.24 K
0.32 K / W / m²

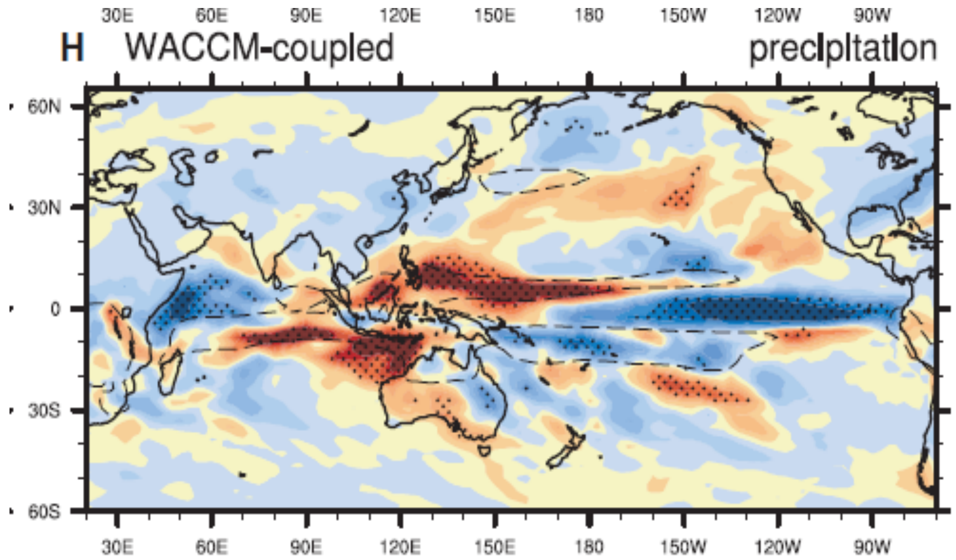
- **Solar forcing efficacy close to 0.3 (smaller than previously thought)**
- **Reduction in global mean SAT response in integrations with chemistry (by 35%)**





hydrological sensitivity
with specified chemistry

d P / d SAT = 2.8 % / K

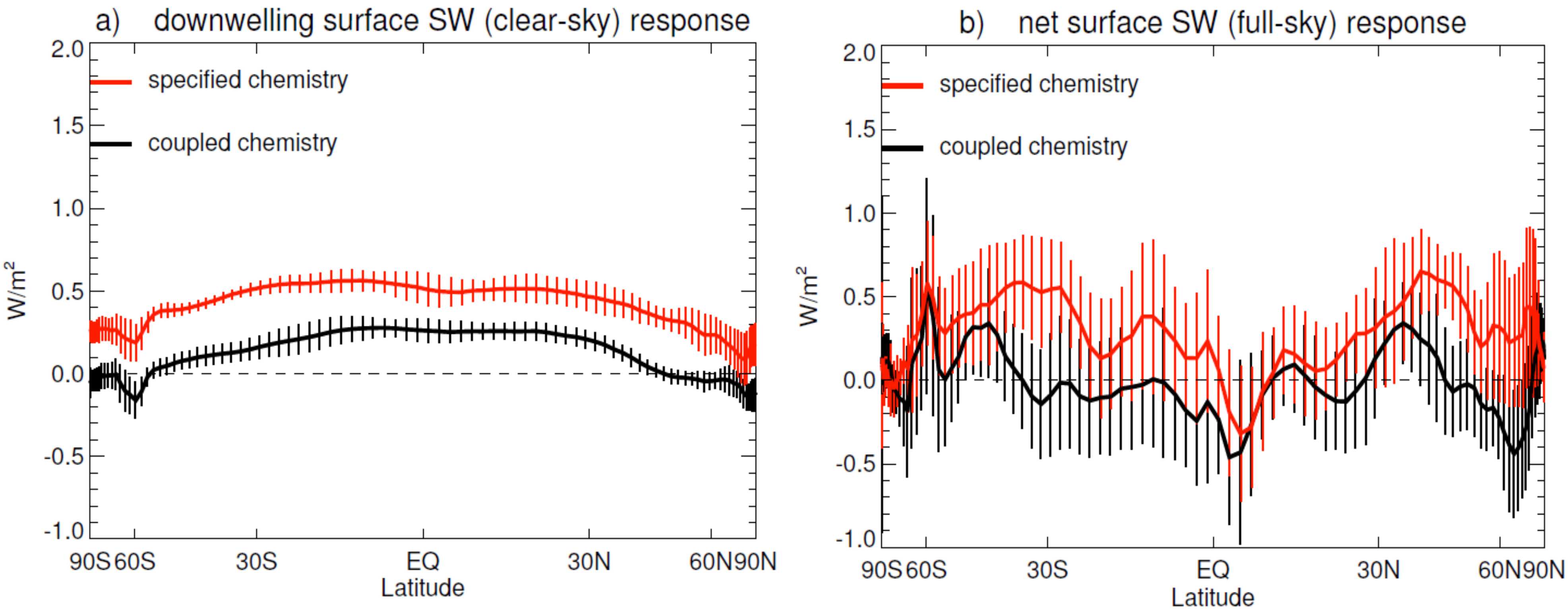


Meehl et al., SCI 2009

hydrological sensitivity
with chemistry

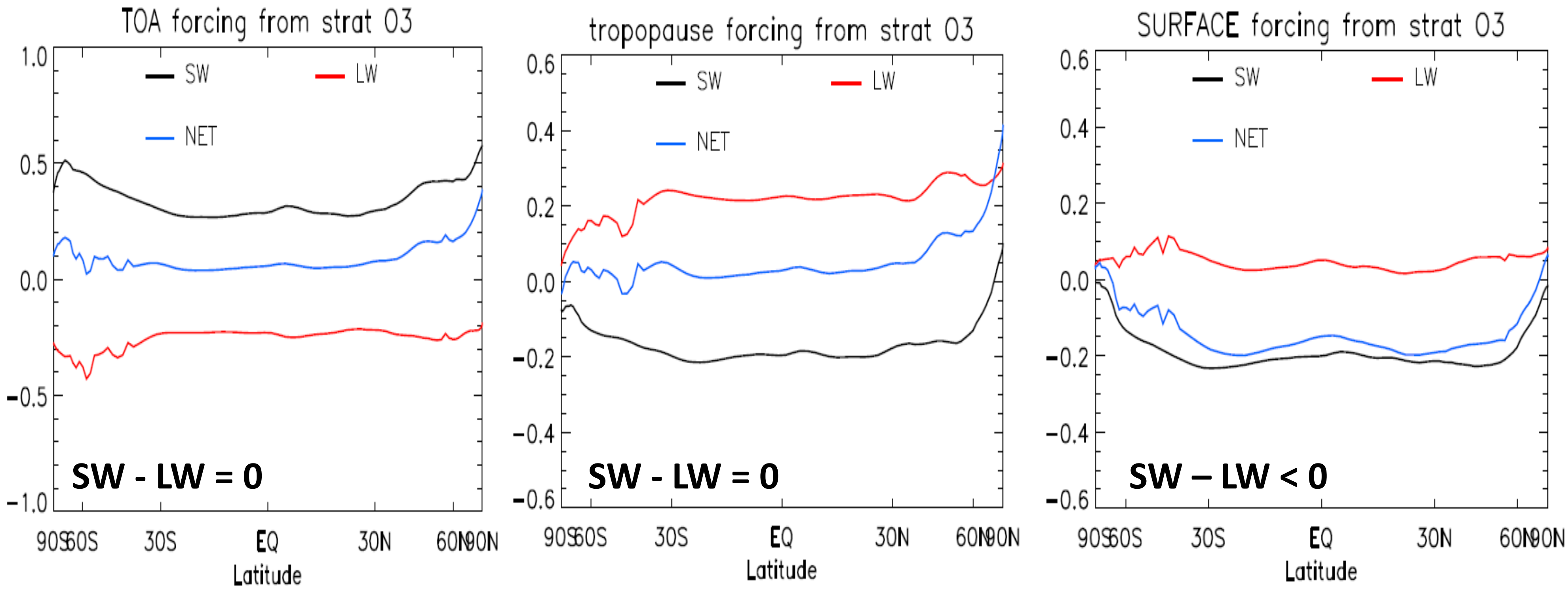
d P / d SAT = 1.7 % / K

Mechanism



- Increase in stratospheric ozone reduces clear-sky SW surface radiation
- Less surface absorption of SW in subtropics and mid-latitudes

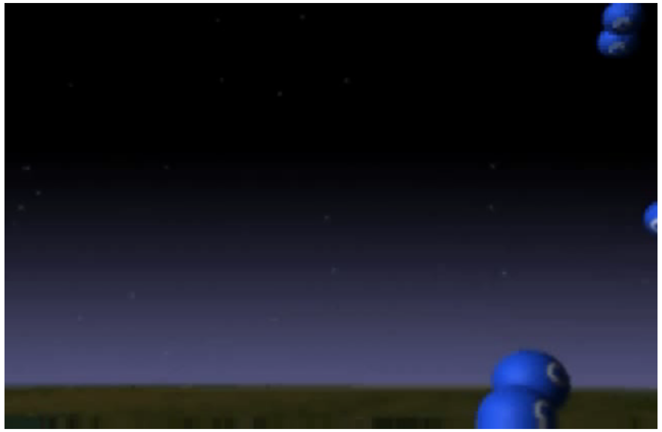
Radiative forcing from UV-induced stratospheric ozone perturbation

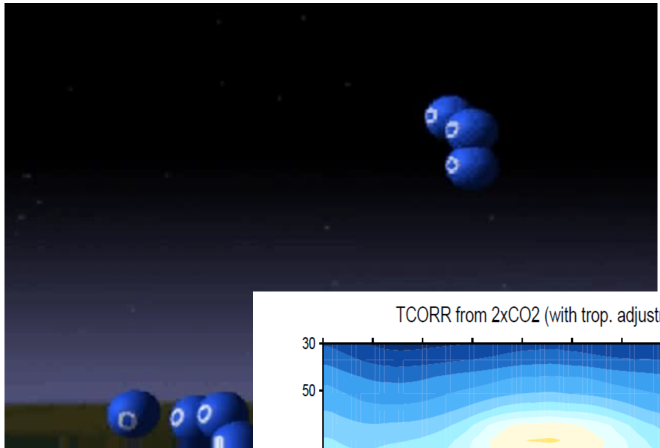


- **Radiative equilibrium** at TOA and tropopause is obtained by partitioning LW and SW differently (sign of net SW and LW forcings changes!)

- **Adjusted radiative forcing at both TOA and tropopause is poor predictor of surface forcing!**

Stratospheric ozone





$O_2 + h\nu$ (**λ < 250 nm**) → O + O

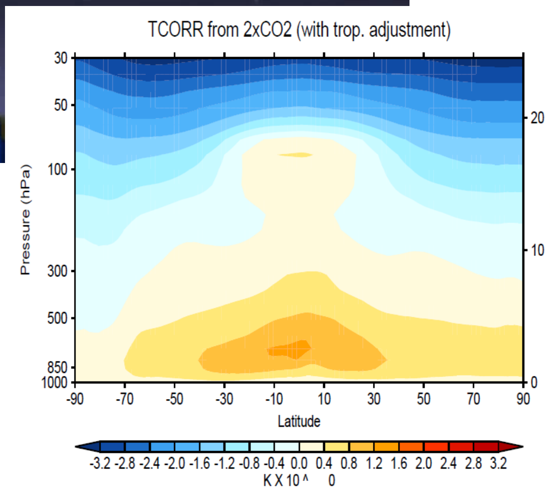
O + O_2 + m → O_3

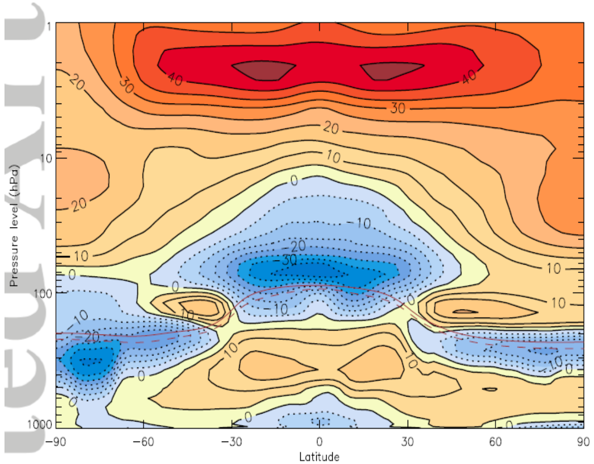
$O_3 + h\nu$ (**λ < 310 nm**) → O_2 + O

O+O_3 → 2O_2

T-dependent rate constant

$$exp(-2060/T)$$





Exponential decay larger with smaller T

↓

Strat.cooling slows down this reaction

↓

O3 increase