Reduction of climate sensitivity to solar forcing due to stratospheric ozone feedback: a study contrasting WACCM and SC-WACCM

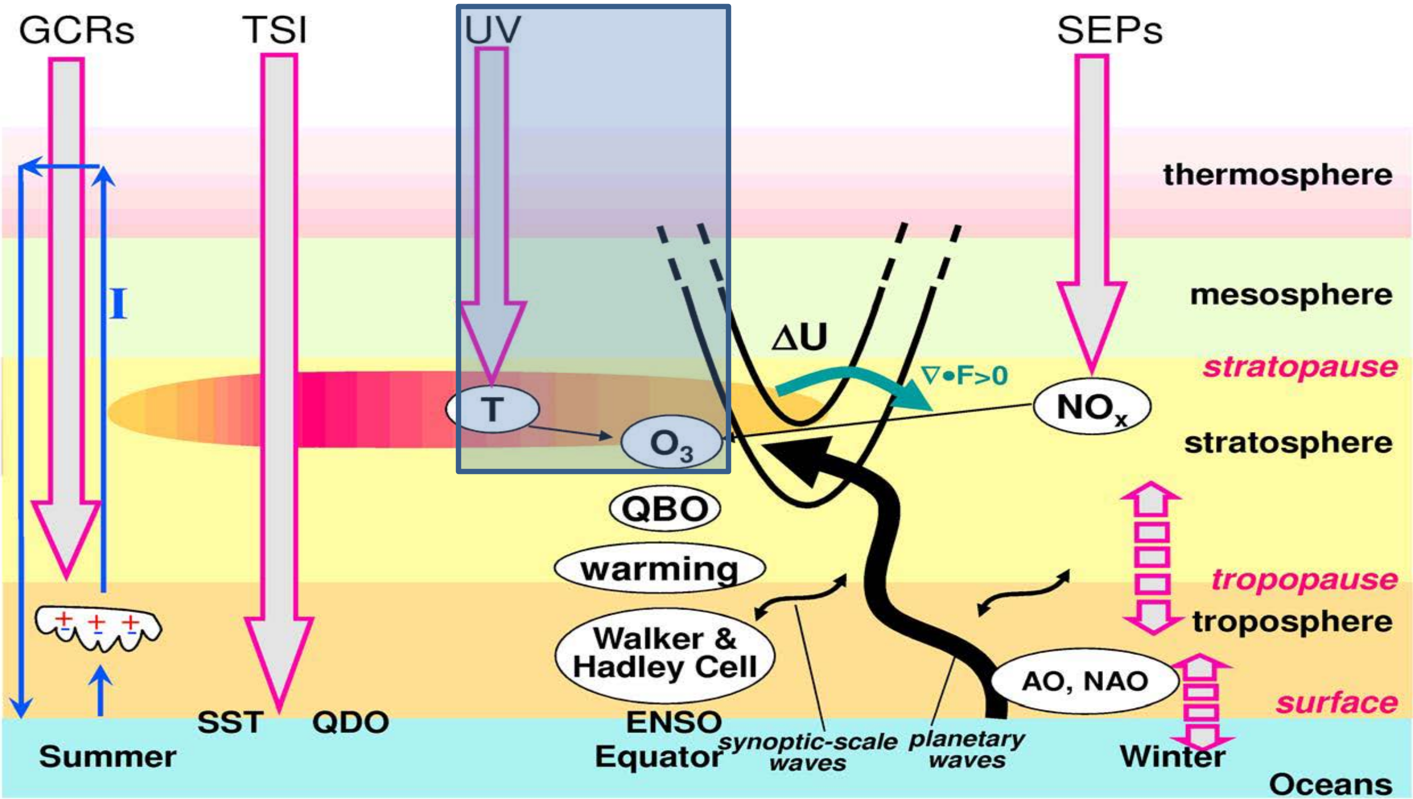
Gabriel Chiodo

Lorenzo Polvani

Columbia University

Boulder, 03/09/2016

Impacts of solar variability on climate: mechanisms



Gray et al., 2010

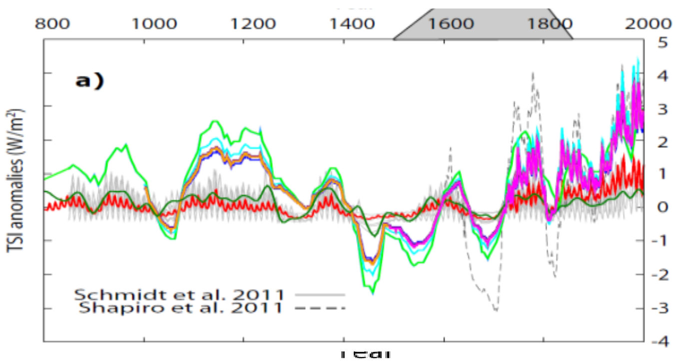
- Impact of solar variability on surface climate not well understood

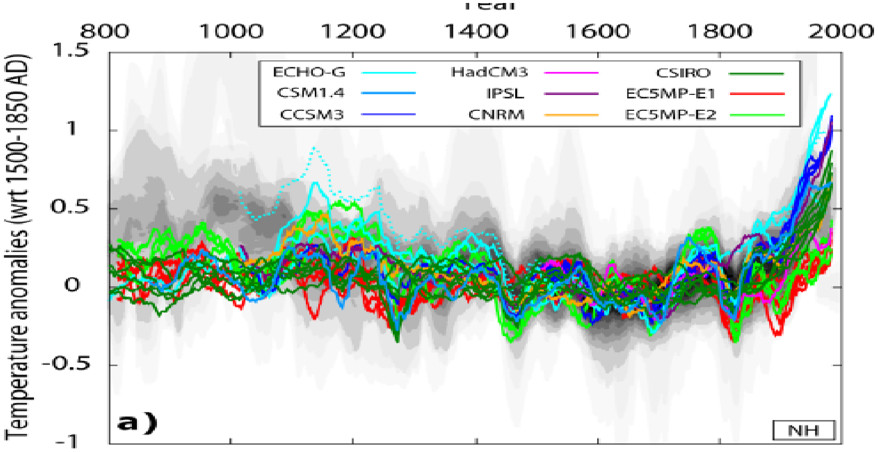
- The most robust impact of 11-year variability is in found in the stratosphere. Important role played by UV-ozone feedback there

An interactive ozone chemistry is needed to capture the O3-UV feedback

- Yet, many earth system models involved in PMIPs, and GEOMIPs did not include an interactive stratospheric chemistry

PMIPs – solar forcing

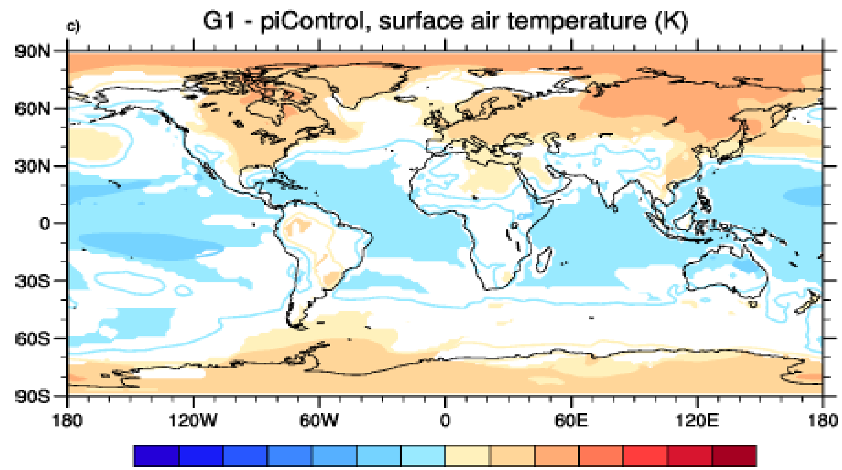




Fernandez-Donado et al., 2013

GEOMIPs – solar forcing

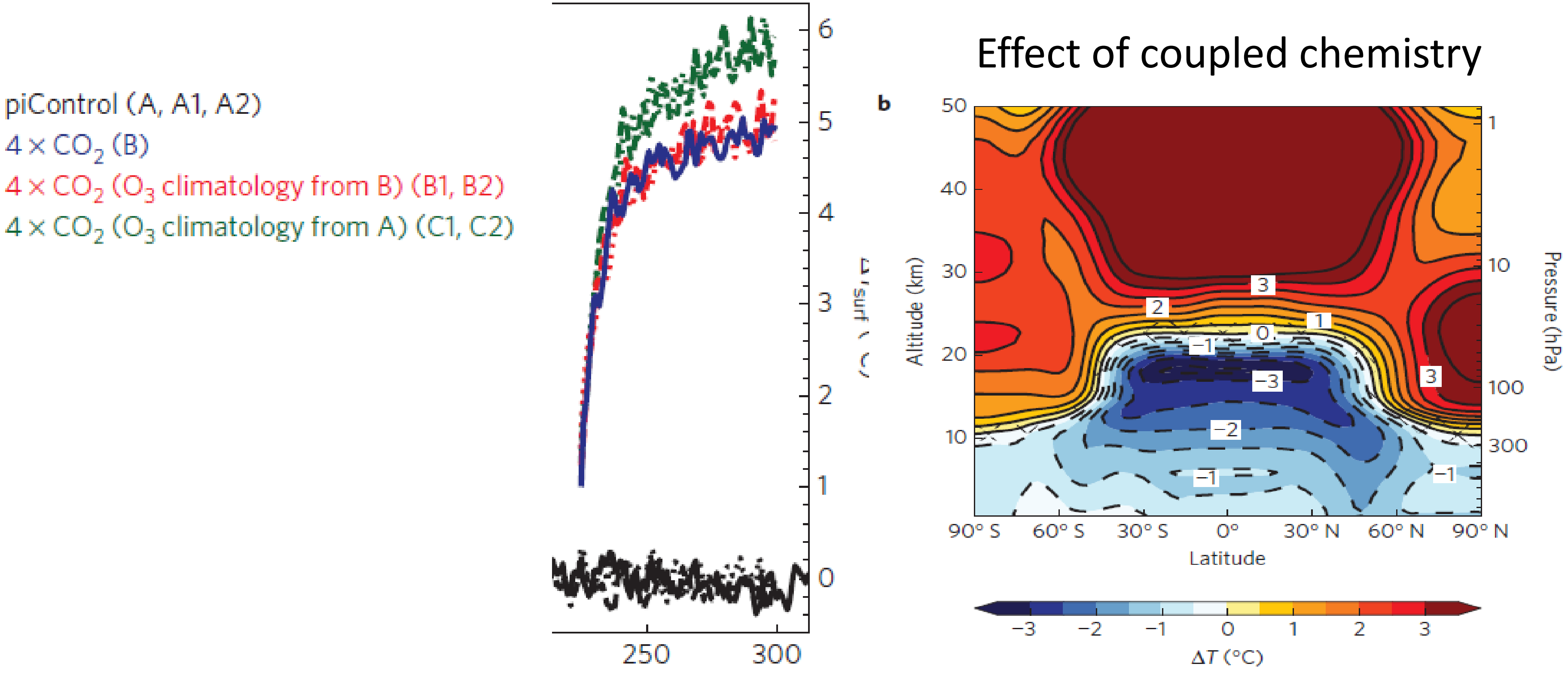
	IPSL-CM5A	MPI-ESM	NorESM	HadGEM2-ES
Forcing from $4 \times CO_2$ ($W\,m^{-2}$)	6.4	9.6	7.5	6.8
TSI reduction in G1 ($W\,m^{-2}$)	48	64	55	53
(percentage)	(3.5 %)	(4.7 %)	(4.0 %)	(3.9 %)
Forcing from TSI reduction ($W\,m^{-2}$)	-8.4	-11.3	-9.6	-9.4



Schmidt et al., 2012

Motivation

- In one model (HadGEM3), it has been shown that interactive chem reduces the equilibrium climate sensitivity



Nowack et al. 2014

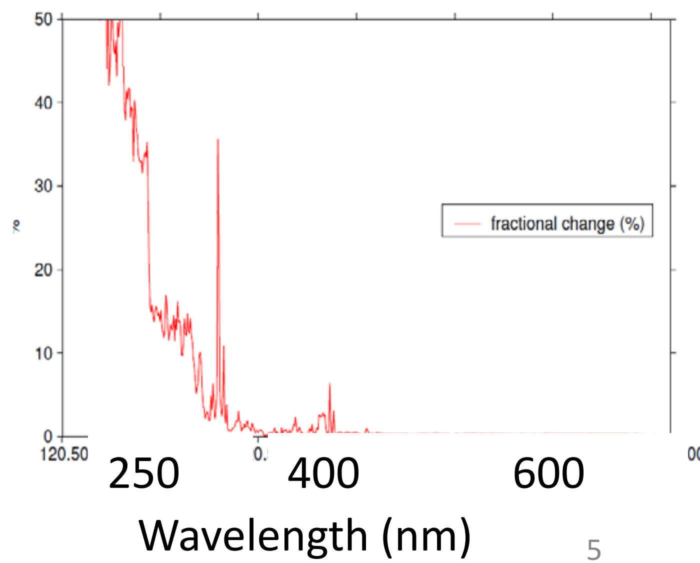
Aim of this work

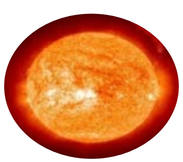
- Examine whether coupled stratospheric chemistry alters the model sensitivity to solar forcing

Model-set up

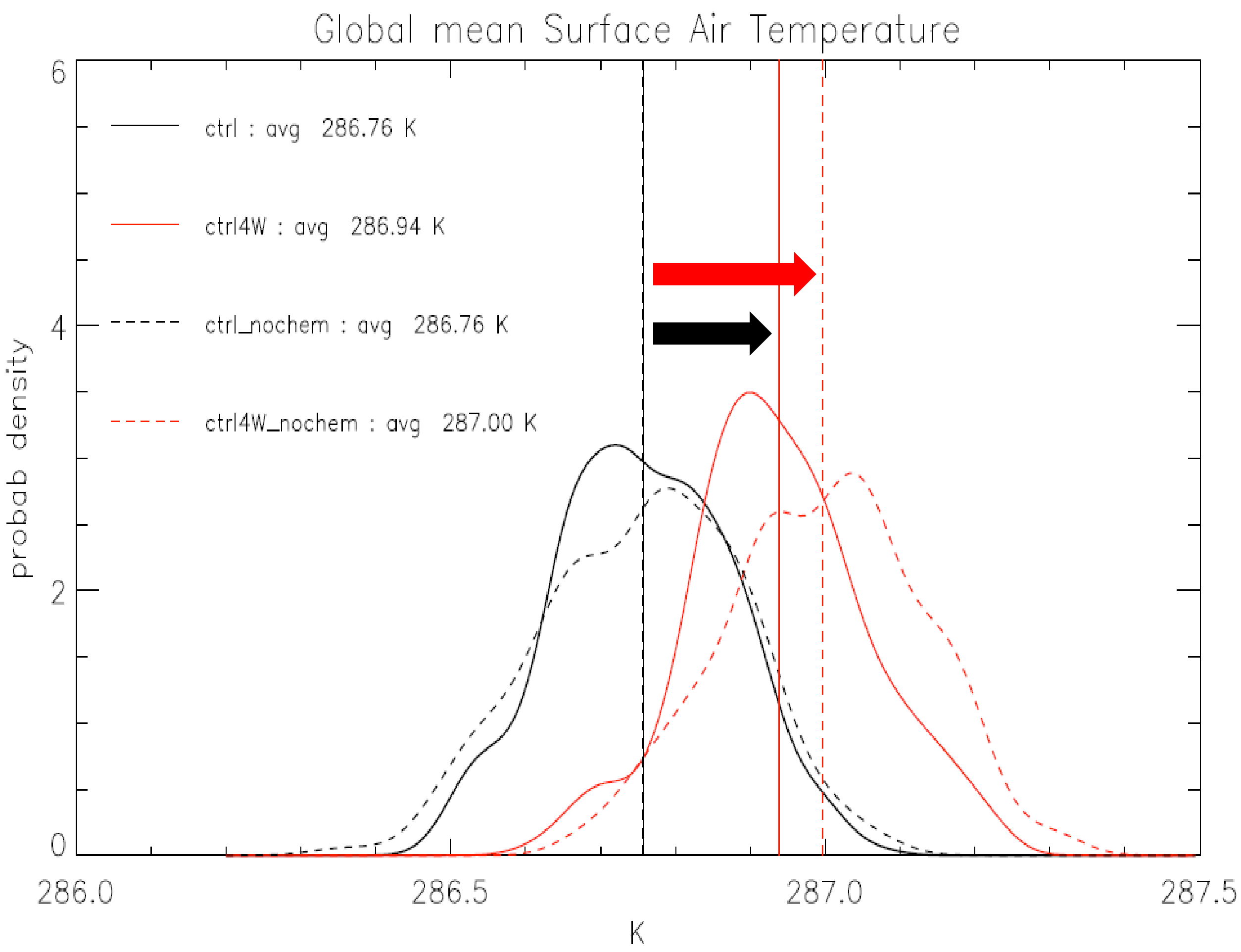
	name	solar	ozone	years
WACCM4 (chemistry)	ctrl	SSI = 1361 W/m^2	interactive	300
	ctrl4W	SSI = 1365 W/m^2	interactive	300
SC-WACCM4 (specified chemistry)	ctrl_nochem	SSI = 1361 W/m^2	ctrl	300
	ctrl4W_nochem	SSI = 1365 W/m^2	ctrl	300

Scycle NRL-SSI, x4 to obtain robust suface response





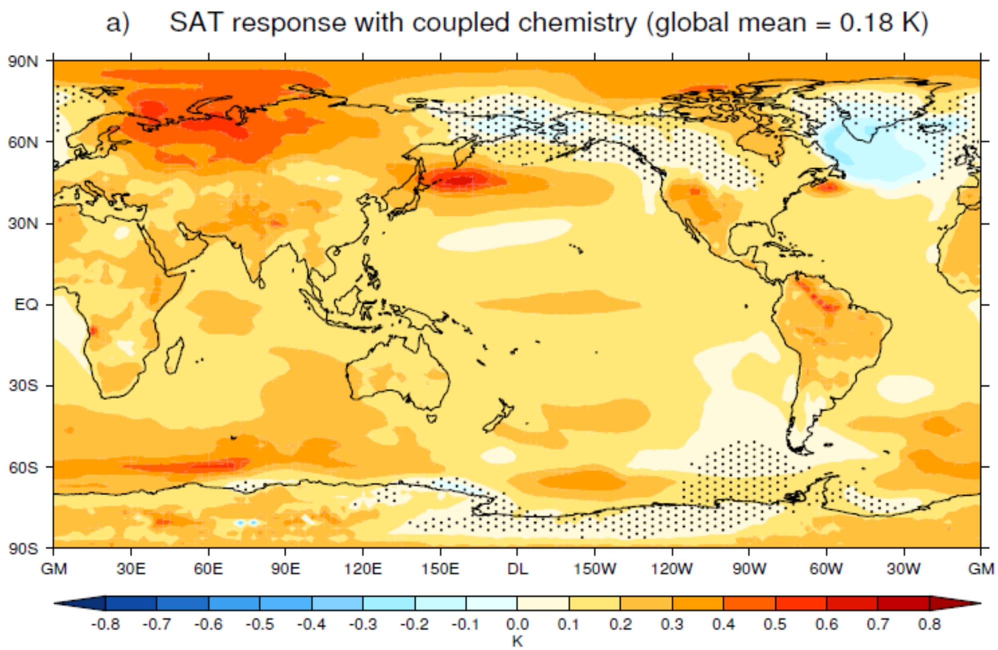
Results

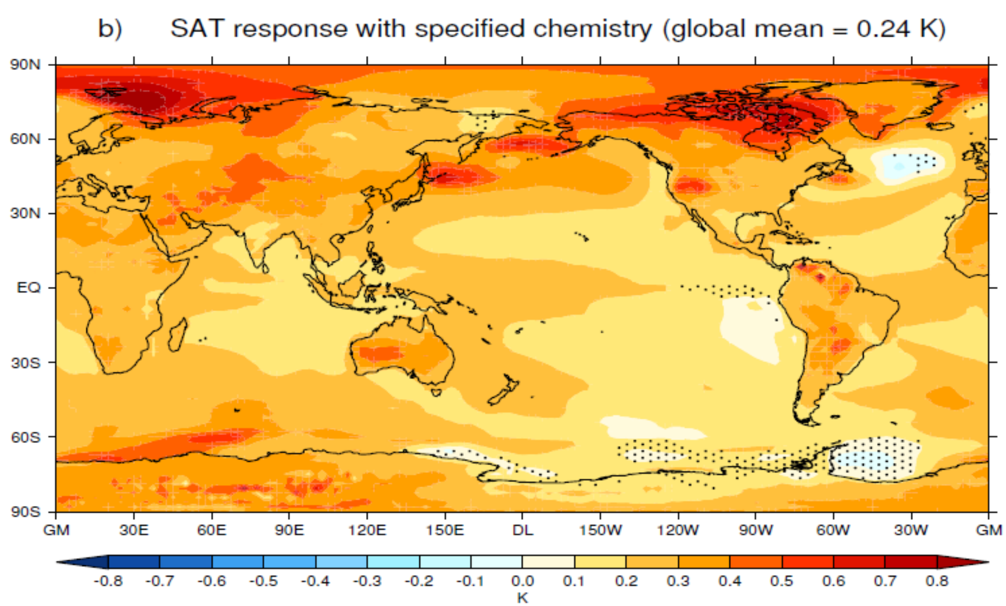


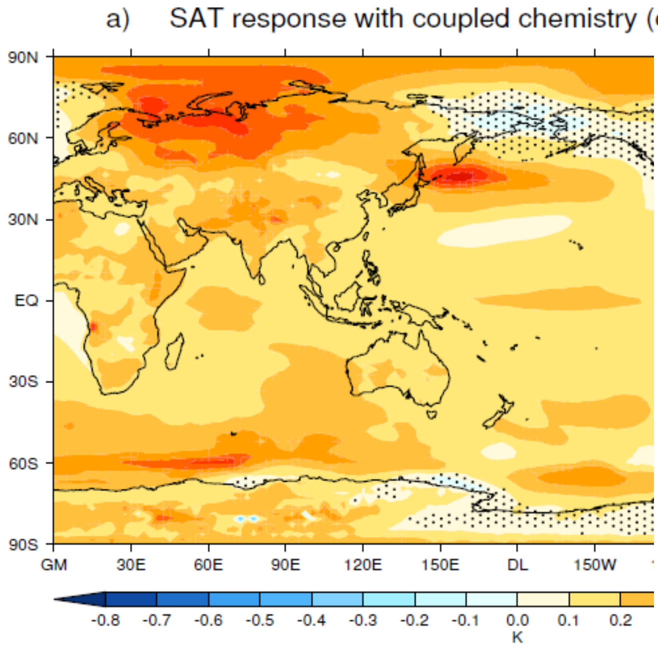
dT_chem = 0.18 K
0.24 K / W / m²

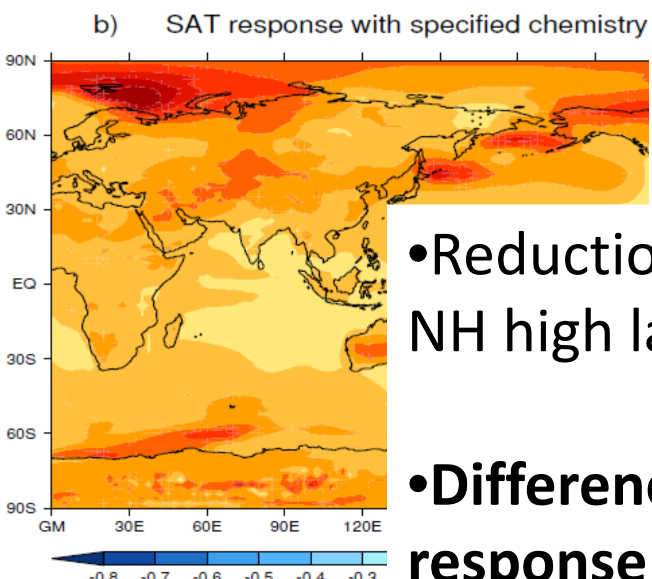
dT_nochem = 0.24 K
0.32 K / W / m²

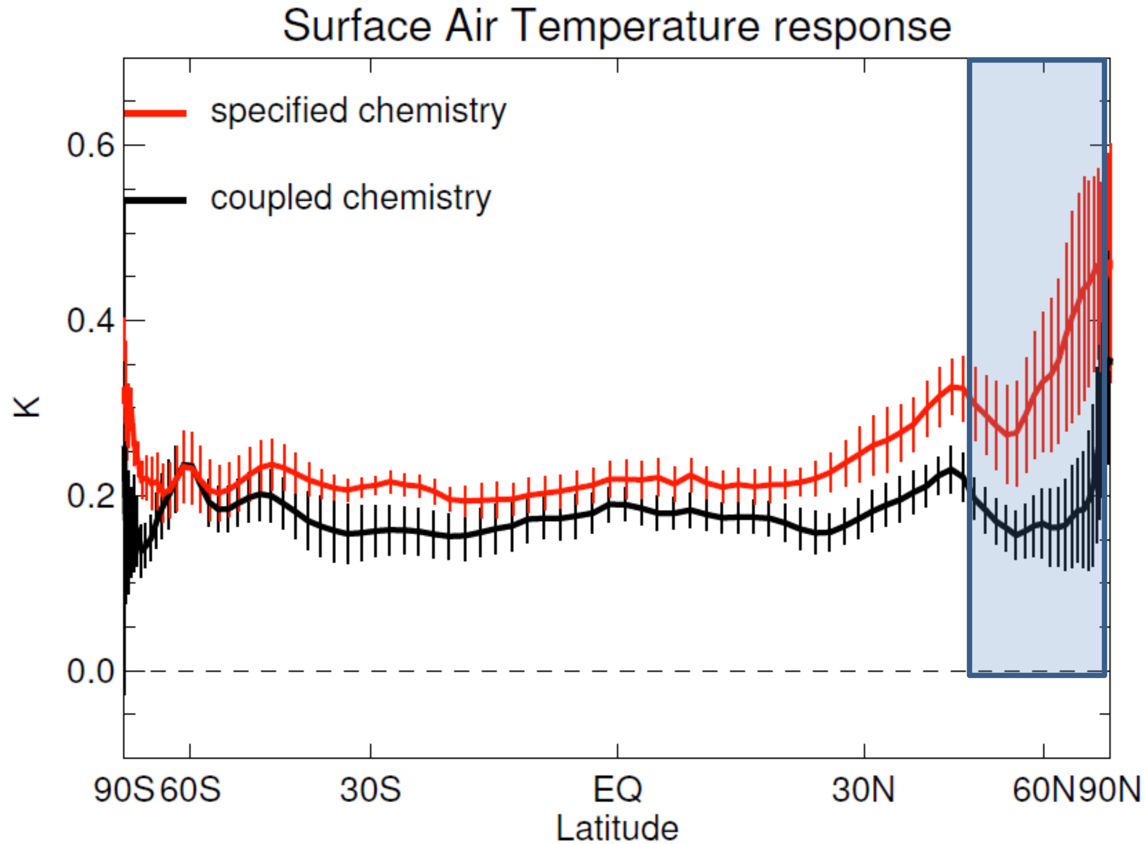
- **Reduction in global mean SAT response in integrations with chemistry (by 35%)**


a) SAT response with coupled chemistry (global mean = 0.18 K)
90N
60N
30N
EQ
30S
60S
90S
GM
30E
60E
90E
120E
150E
DL
150W
120W
90W
60W
30W
GM
-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
K


b) SAT response with specified chemistry (global mean = 0.24 K)
90N
60N
30N
EQ
30S
60S
90S
GM
30E
60E
90E
120E
150E
DL
150W
120W
90W
60W
30W
GM
-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
K

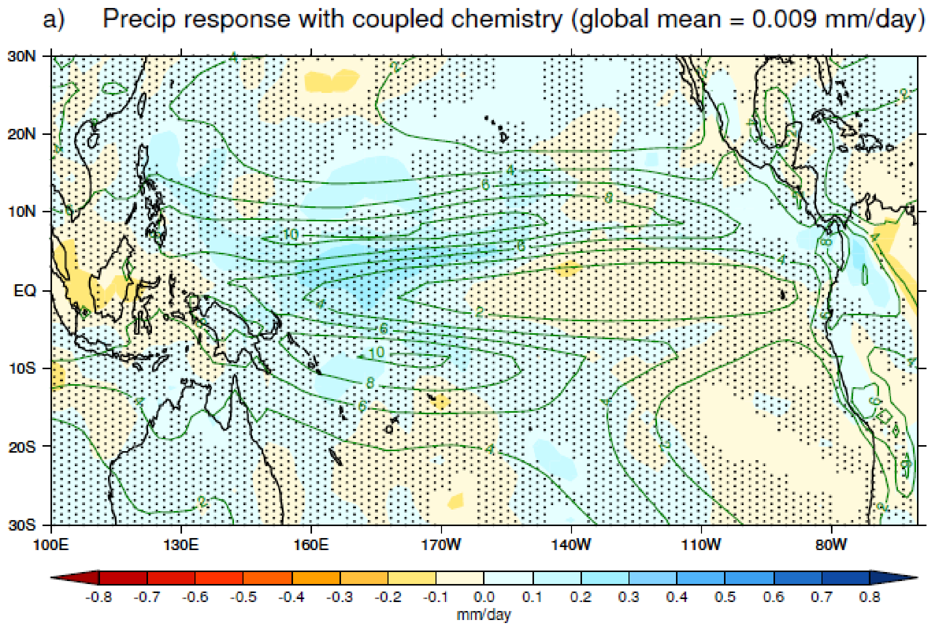






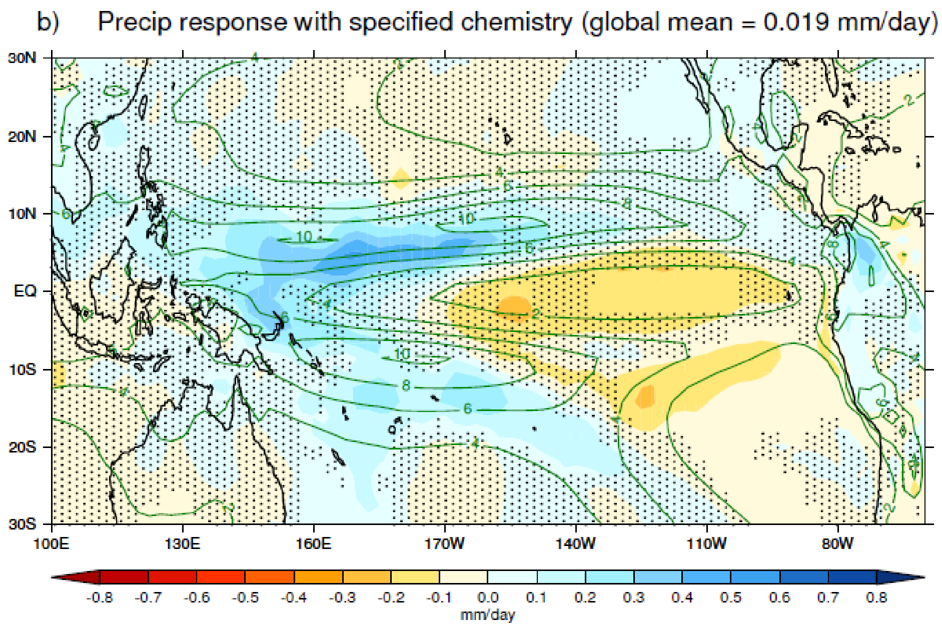
- Reduction of response in chemistry run, especially in NH high latitudes

- **Difference chem vs nochem can be as large as the response itself**



hydrological sensitivity with chemistry

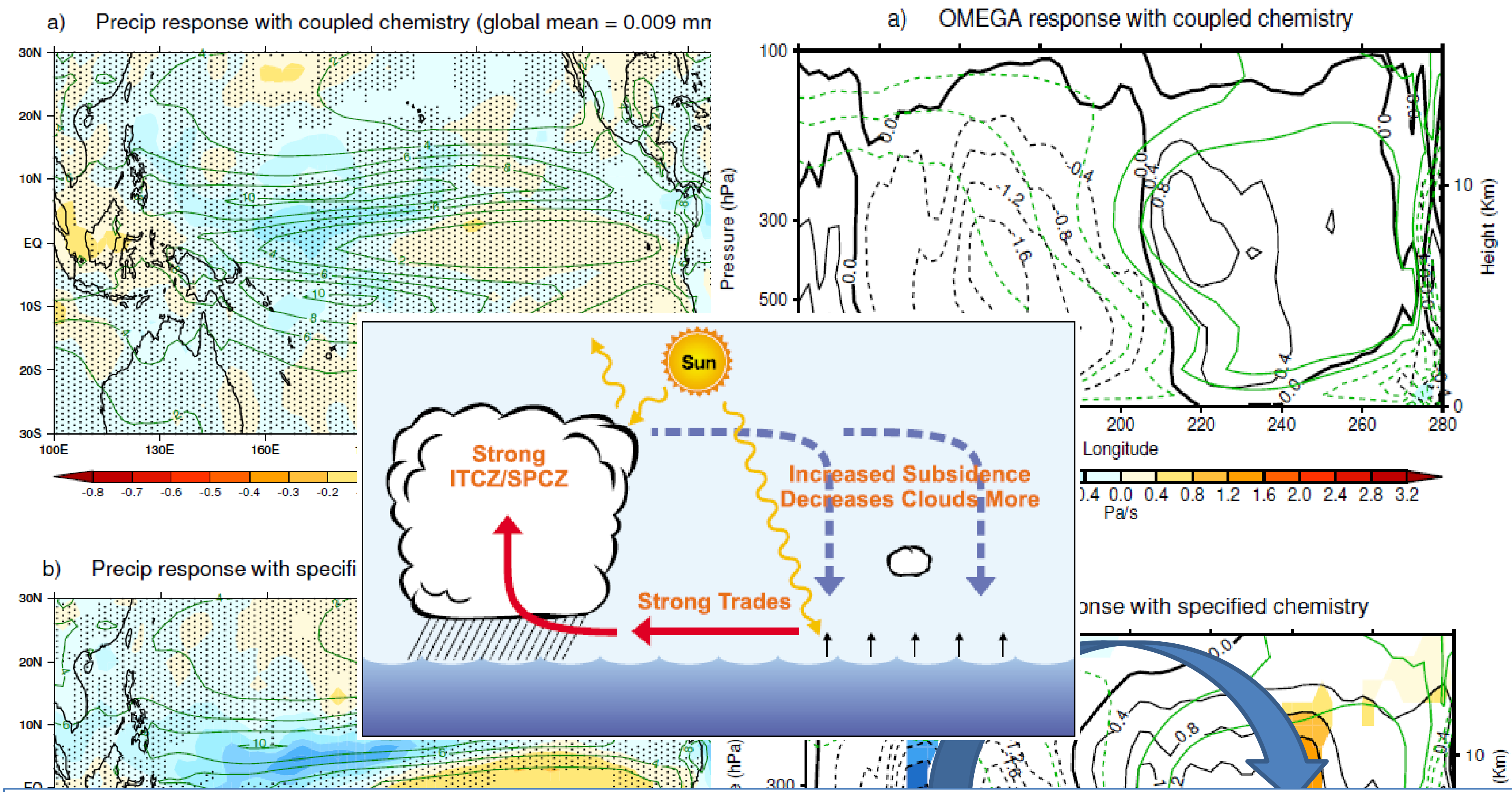
d P / d SAT = 1.7 % / K



hydrological sensitivity with specified chemistry

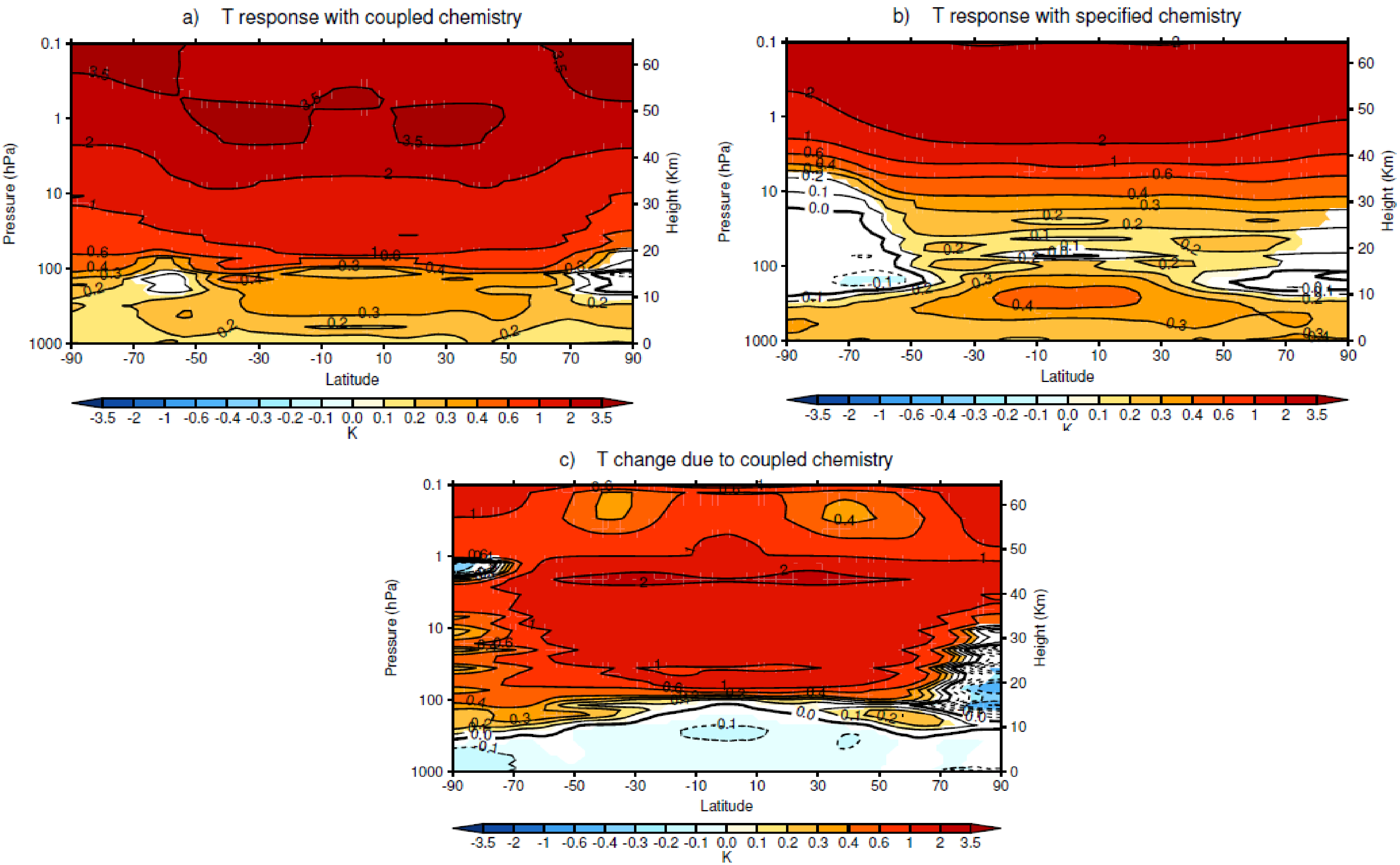
d P / d SAT = 2.8 % / K

→ In agreement with HadGEM1 model (Andrews et al., 2010)

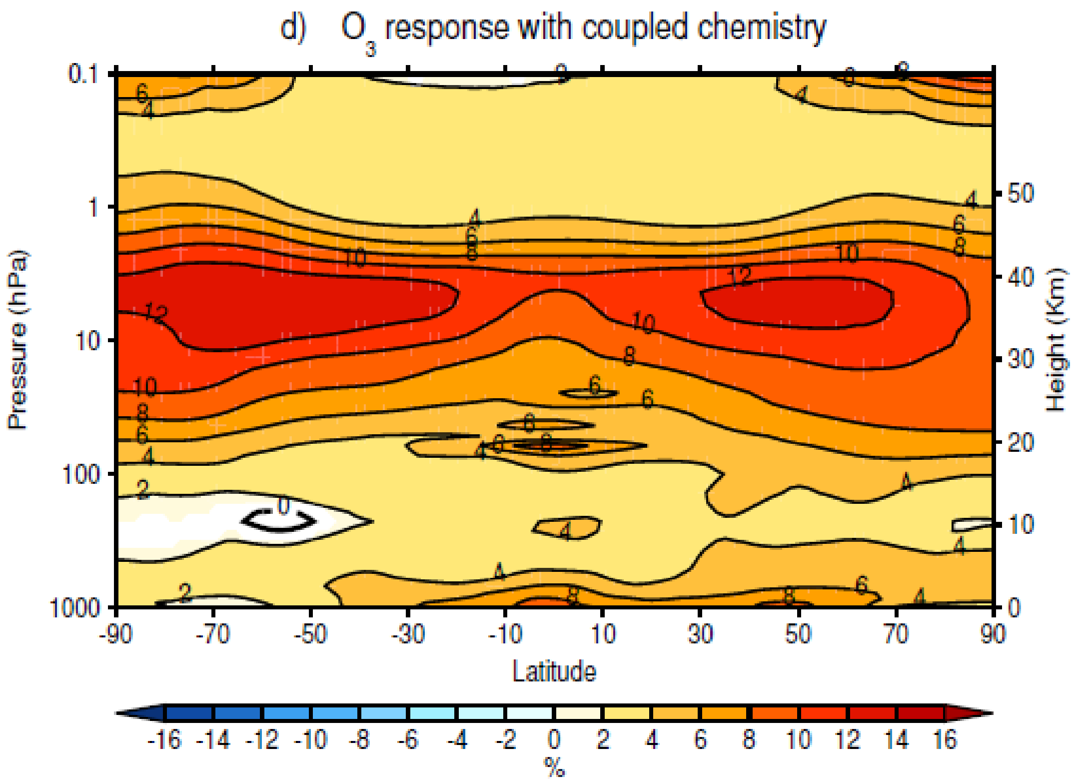


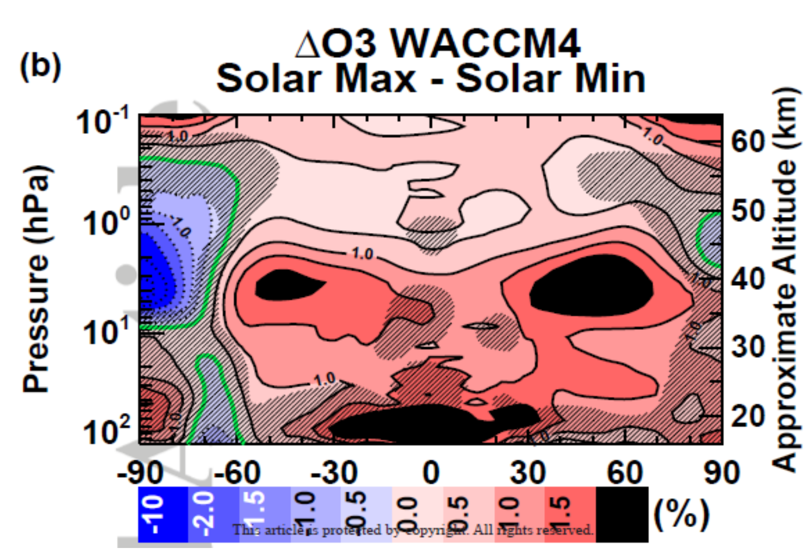
- Stronger Walker-Cell in runs without chemistry. Consistent with bottom-up mechanism (Meehl et al., 2009)

- **However, much weaker response with chemistry**



- The chemistry amplifies the stratospheric warming response (2x)
- Opposite effect in the troposphere (i.e., cooling)

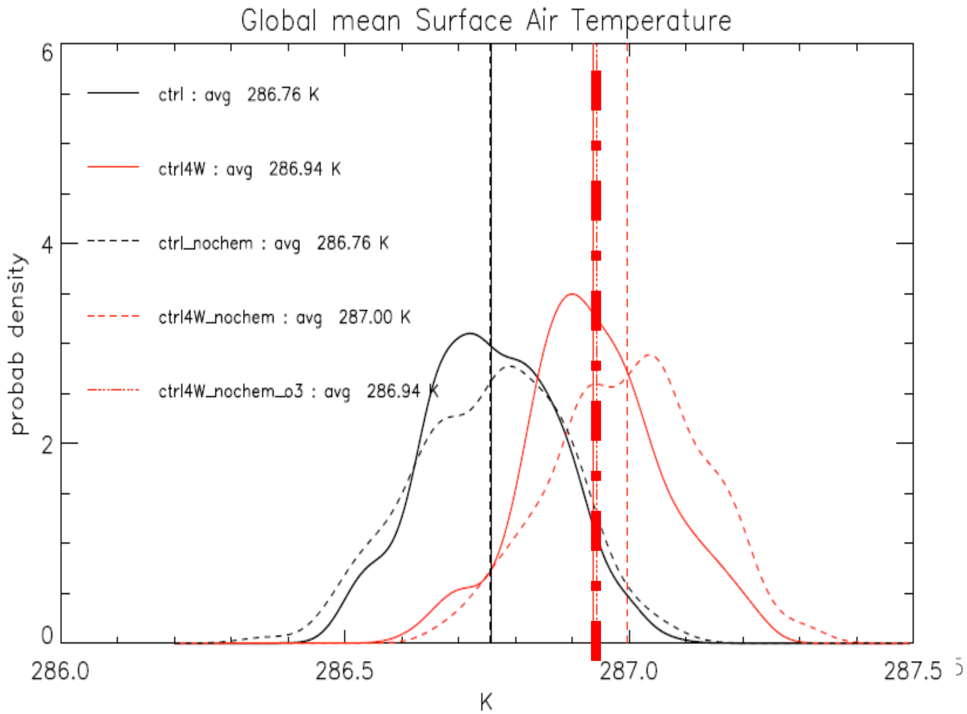


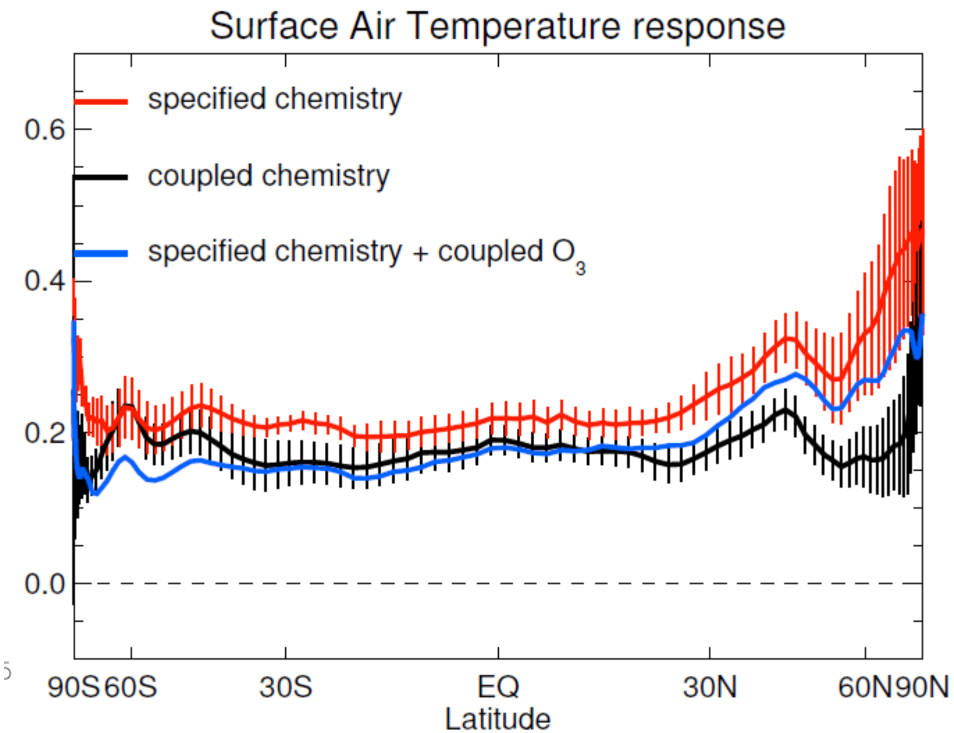


Peck et al., 2015

- Realistic ozone response (similar to 11-yr response - 4x larger)
- Is ozone responsible for reduced surface warming in WACCM?

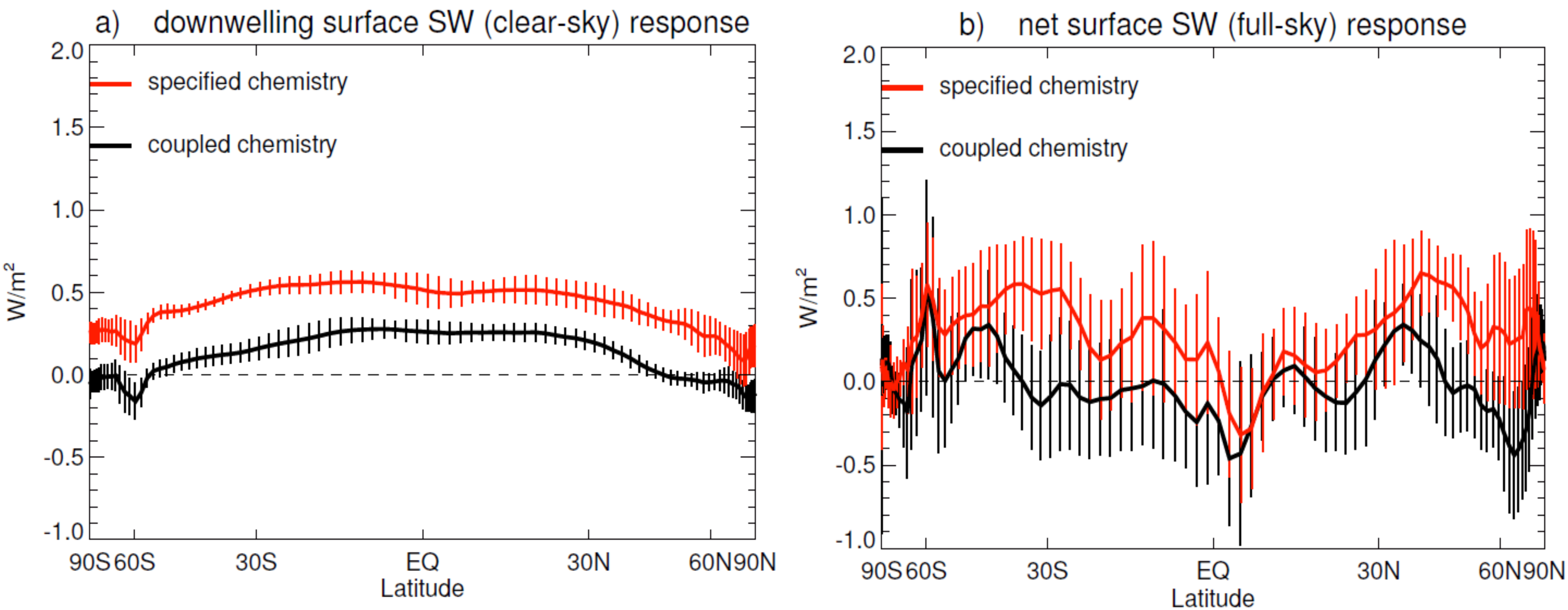
Does ozone cause the differences in surface response?





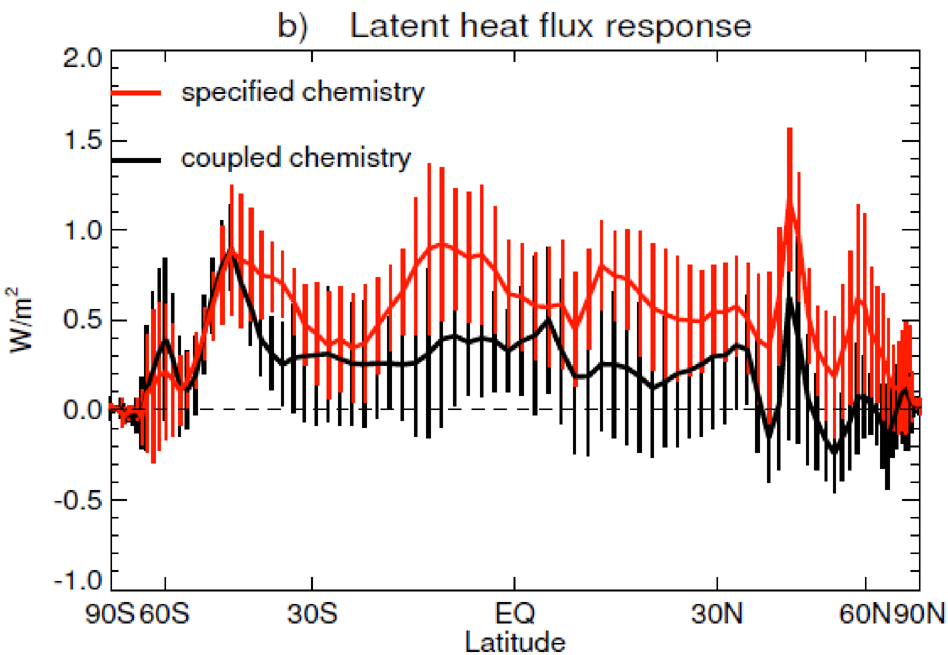
- By specifying ozone from perturbed WACCM run in SC-WACCM, we reproduce the WACCM response
- Thus, UV-ozone feedback responsible for reduced WACCM sensitivity

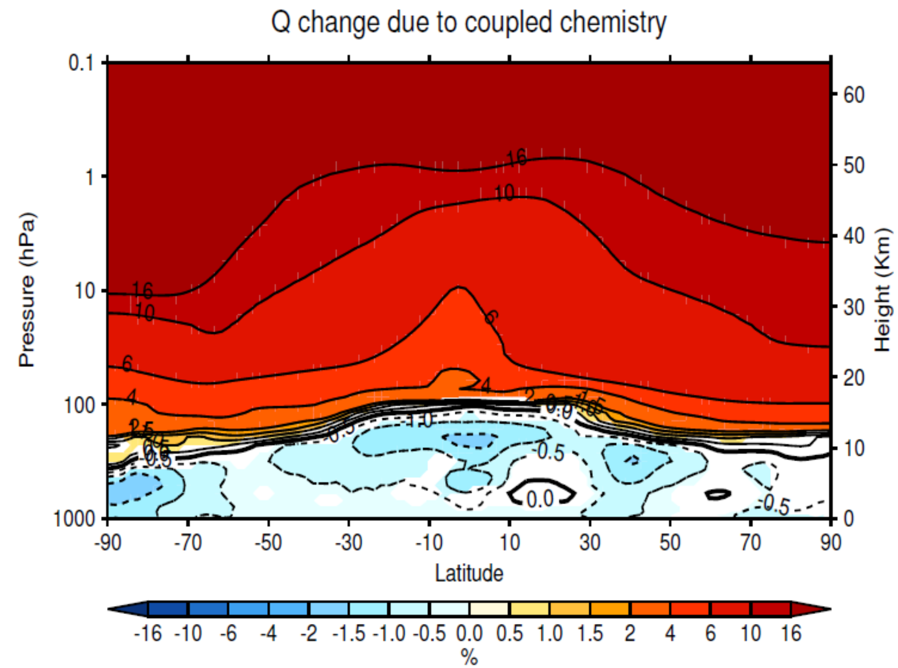
Mechanism



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

Feedback from tropospheric moisture ?

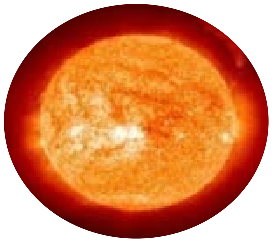




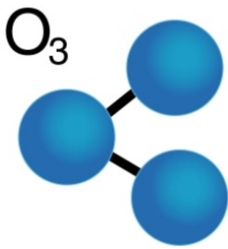
- Decrease in absorbed clear-sky SW in chemistry runs → less evaporation than in specified chemistry integrations

- Upper tropospheric moisture change amplifies chem vs nochem diff

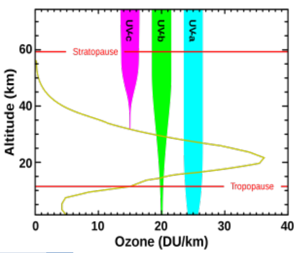
Mechanism for ozone-sensitivity



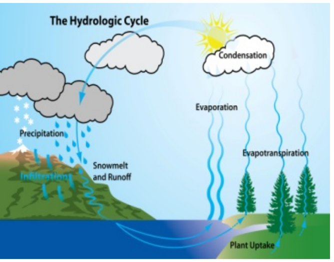
UV forcing enhances O3 production (O2 photol.)



Increasing O3 “filters” more UV (Hartley-Huggins), and VIS irradiance (Chappuis band)



Reduced surface SW radiation (mostly VIS) limits surface warming



Weaker evaporation+precipitation response.

Less tropospheric moisture (LW-feedback)

Conclusions

- The stratospheric ozone feedback reduces the model sensitivity to solar forcing
  - Consistent with reduction in sensitivity to GHGs in other models (Nowack et al., 2014). Yet, mechanism fundamentally different

- Models without interactive chemistry (PMIP and GEOMIP) might overestimate climate sensitivity to solar forcing

- Prescribing ozone consistent with imposed solar forcing is viable approach to reduce this potential bias

Chiodo and Polvani, submitted to Journal of Climate (2016)

THANK YOU!