The impact of stratospheric ozone chemistry on climate sensitivity

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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?

\[ \frac{dT_s}{dCO_2} = . \]

Is full O3-climate interaction needed in models?
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

Marsh et al. GRL 2016

• Impact on ECS in other models:

**HADGEM**
- $4xCO2_{intO3} = 4.8$ K
- $4xCO2_{fixO3} = 5.9$ K

**ECHAM-MESSY**
- $4xCO2_{intO3} = 7.5$ K
- $4xCO2_{fixO3} = 8.1$ K

**SOCOL**
- $4xCO2_{intO3} = 7.5$ K
- $4xCO2_{fixO3} = 8.0$ K

$O3$ effect $= -20\%$

Nowack et al. NCC 2014

$O3$ effect $= -8\%$

Diemuller et al., 2014

$O3$ effect $= -8\%$

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)?
Aim of this work

• Quantify the model response to 4xCO2 in WACCM, without any changes in CFCs. Hence, we quantify CO2-driven O3 feedback!

• Examine whether stratospheric ozone chemistry feedbacks alter the SH circulation response to 4xCO2

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)
• No effect of stratospheric ozone chemistry on surface response

• Yet, effect in lower stratosphere very significant (50% of CO2 signal)
Temperature-ozone link

**Zonal mean Temp. change due to interactive O3**

**Zonal mean Ozone response to 4xCO2**

- Change in temperature gradient caused by ozone response to CO2
Zonal wind (annual mean)

4xCO2 response

change due to interactive O3

• Response of eddy-driven jet is opposite of that caused by CO2
Surface effects of ozone feedback: eastward wind stress

4xCO2 response

Change due to interactive O3

Pa (x 0.01)

Pa (x 0.01)

• 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

\[
\Psi_M = \frac{2\pi a \cos \phi}{g} \int_0^P \nu dp
\]

Change due to interactive O3
Summary and conclusions

1) The effects of stratospheric ozone chemistry on the modeled surface temperature response to CO2 are small (and model dependent).

2) However, the response of stratospheric ozone to 4xCO2 is robust across models (decrease in tropics, increase over polar cap).

3) The stratospheric ozone response to 4xCO2 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 CO2**, due to their missing representation of negative ozone feedback on the dynamics.
THANK YOU!

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EXTRA SLIDES
Northern Hemispheric spring (MAM)

4xCO2 response

Sea Level Pressure

Change due to interactive O3

Precipitation

Change due to interactive O3
CAVEATS

• Boundary conditions (spec. Values) for CH4 under 1850 conditions

• Methane oxidation still on in SC-WACCM
• Intermodel differences likely caused by strat. water vapour feedback
Results

\[
\begin{align*}
\text{dT}_\text{chem} &= 0.18 \text{ K} \\
0.24 \text{ K} / \text{W} / \text{m}^2 \\
\text{dT}_\text{nochem} &= 0.24 \text{ K} \\
0.32 \text{ K} / \text{W} / \text{m}^2 \\
\end{align*}
\]

- 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

\[
\frac{d P}{d \text{SAT}} = 2.8 \% / K
\]

In agreement with HadGEM1 model (Andrews et al., 2010) and Meehl et al., SCI 2009

hydrological sensitivity with chemistry

\[
\frac{d P}{d \text{SAT}} = 1.7 \% / K
\]
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

\[ \text{O}_2 + \text{hv} (\lambda < 250 \text{ nm}) \rightarrow \text{O} + \text{O} \]

\[ \text{O} + \text{O}_2 + \text{m} \rightarrow \text{O}_3 \]

\[ \text{O}_3 + \text{hv} (\lambda < 310 \text{ nm}) \rightarrow \text{O}_2 + \text{O} \]

\[ \text{O} + \text{O}_3 \rightarrow 2\text{O}_2 \]

T-dependent rate constant

\[ e^{\frac{-2060}{T}} \]

Exponential decay larger with smaller T

\[ \text{Strat.cooling slows down this reaction} \]

\[ \text{O}_3 \text{ increase} \]