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

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Impacts of solar variability on climate: mechanisms

- Impact of solar variability on surface climate not well understood.
- The most robust impact of 11-year variability is 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.
Motivation

• In one model (HadGEM3), it has been shown that interactive chemistry reduces the equilibrium climate sensitivity.

Effect of coupled chemistry

Nowack et al. 2014
Aim of this work

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

Model-set up

<table>
<thead>
<tr>
<th>name</th>
<th>solar</th>
<th>ozone</th>
<th>years</th>
</tr>
</thead>
<tbody>
<tr>
<td>ctrl</td>
<td>SSI = 1361 W/m²</td>
<td>interactive</td>
<td>300</td>
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<tr>
<td>ctrl4W</td>
<td>SSI = 1365 W/m²</td>
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<td>300</td>
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<tr>
<td>ctrl_nochem</td>
<td>SSI = 1361 W/m²</td>
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<td>ctrl4W_nochem</td>
<td>SSI = 1365 W/m²</td>
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<td>300</td>
</tr>
</tbody>
</table>

Scycle NRL-SSI, x4 to obtain robust surface response
Results

\[ dT_{\text{chem}} = 0.18 \, \text{K} \]
\[ 0.24 \, \text{K} / \text{W} / \text{m}^2 \]

\[ dT_{\text{nochem}} = 0.24 \, \text{K} \]
\[ 0.32 \, \text{K} / \text{W} / \text{m}^2 \]

- Reduction in global mean SAT response in integrations with chemistry (by 35%)
a) SAT response with coupled chemistry (global mean = 0.18 K)

b) SAT response with specified chemistry (global mean = 0.24 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

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

hydrological sensitivity with specified chemistry

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

→ 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)
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.
• 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 $\rightarrow$ 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
THANK YOU!

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