Whole Atmosphere Simulation of Anthropogenic Climate Change

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Global mean temperature, density, and composition study for doubled and halved CO$_2$ and CH$_4$. 

Model Prediction of Global Change in the Thermosphere

Roble & Dickinson [1989]
Observed / Inferred Global Change Scenario:
“Warm Down, Cool Up”

Ionosonde Data

Satellite Drag Data

Radar, Lidar; Rocketsonde; Airglow; Satellite; etc.

Lastovicka et al., 2006
证据来自卫星拖曳对上层大气全球变化的证据，但受太阳活动的影响

(a) 空气密度 (ng/m³)

大约5% / 十年减少在太阳活动的最小值

Top: 全球平均中性密度在400 km，81天平均和年度平均

Emmert et al., 2010; (c.f., Keating et al., 2000; Marcos et al., 2005; Saunders et al., 2010)
Whole Atmosphere Community Climate Model – eXtended (WACCM-X)

WACCM-X is WACCM with additional physics and extended vertical range through the thermosphere/ionosphere (~500km)

Whole Atmosphere Community Climate Model (WACCM) is CAM with additional chemistry/physics and extended vertical range into the lower thermosphere (~120km)

Community Atmosphere Model (CAM) is atmospheric component of CESM

NCAR Community Earth System Model (CESM)
Recent Progress on WACCM-X

• Ion and electron energetics implemented:
  — Now calculating $T_i$ and $T_e$ in WACCM-X.

• Equatorial electrodynamo installed:
  — Mostly parallel, ESMF interpolation from geographic to geomagnetic coords.

• Ionospheric dynamics implemented:
  — Vertical diffusion and horizontal transport of $\text{O}^+$ in the upper ionosphere.

• Variable mean molecular mass and heat capacity ($C_p$) included in dynamical core

• Capability for using Assimilative Mapping of Ionospheric Electrodynamics (AMIE)

• WACCM-X v. 2.0 released as a component of CESM 2, June 2018
  (but still based on CAM 4 physics)

• WACCM-X v. 2.1 released as a component of CESM 2.1, January 2019

WACCM-X Simulation of a Geomagnetic Storm

Number Density (sum of O2+, NO+, N2+, O+)

Time: 2013-03-17 00:00:00 — 2013-03-17 00:05:00
WACCM-X Global Change Simulation Methodology

• Solar minimum conditions:
  $F_{10.7} = 70$, $K_p = 0.3$

• Solar maximum conditions:
  $F_{10.7} = 200$, $K_p = 0.3$

• Four sets of five-year runs to simulate change in a 29-year interval:
  two with CO$_2$, CH$_4$, and CFCs from 1972–1976
  two with CO$_2$, CH$_4$, and CFCs from 2001–2005
  secular change of geomagnetic field is included

• Full WACCM-X free-running climate simulations
  but using specified SSTs — no interactive ocean or sea ice, etc.
  2° resolution using FV dycore

• Decadal change rates estimated by scaling from 29-year interval to 10 years
Anthropogenic Global Change, 1974 to 2003

- CO$_2$
- CH$_4$
- O$_3$
- H$_2$O
Zonal Mean Temperature Change, 1974 to 2003
Solar Minimum, 5-Year Annual Averages
Zonal Mean Temperature Change, 1974 to 2003
Solar Maximum, 5-Year Annual Averages
Global Annual Mean Temperature Change, 1974 to 2003
Solar Minimum Conditions

- At 110 km, Atmospheric contraction is observed: 
  \( \Delta h = 0.3 \text{ km/decade} \)

1972 to 1976
1972 to 1976
2001 to 2005
2001 to 2005
Global Annual Mean Temperature Change, 1974 to 2003

Solar Maximum Conditions

(a) 1972 to 1976
    2001 to 2005

(b) 1972 to 1976
    2001 to 2005

(c) 1972 to 1976

(d) 1972 to 1976
Interannual Variability of Global Mean Temperature
Solar Minimum Conditions

Comparison with Lidar observations
see Yuan et al., JGR (2019)
doi:10.1029/2018JD029828
and talk in workshop on Wednesday
## Summary of Results for Thermospheric Density at 400 km
(all in percent per decade)

<table>
<thead>
<tr>
<th>( \Delta \rho ) at 400 km Altitude</th>
<th>Low Solar Activity</th>
<th>Average Solar Activity</th>
<th>High Solar Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keating et al. (2000)</td>
<td>-5 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marcos et al. (2005)</td>
<td></td>
<td>-1.7% to -2.4%</td>
<td></td>
</tr>
<tr>
<td>Emmert et al. (2008)</td>
<td>-5.5 ± 1.4 %</td>
<td></td>
<td>-2 ± 1 %</td>
</tr>
<tr>
<td>Saunders et al. (2011)</td>
<td>-7 %</td>
<td></td>
<td>-4 %</td>
</tr>
<tr>
<td>Emmert et al. (2015)</td>
<td></td>
<td>-2 ± 0.5 %</td>
<td></td>
</tr>
<tr>
<td><strong>Models</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roble &amp; Dickinson (1989)</td>
<td></td>
<td>-3 %</td>
<td></td>
</tr>
<tr>
<td>Rishbeth &amp; Roble (1992)</td>
<td></td>
<td>-2 %</td>
<td></td>
</tr>
<tr>
<td>Qian et al. (2006)</td>
<td>-2.5 %</td>
<td>-1.7 %</td>
<td>-0.8 %</td>
</tr>
<tr>
<td>Akmaev et al. (2000, 2006)*</td>
<td></td>
<td>-3% to -5 %</td>
<td>-3% to -5 %</td>
</tr>
<tr>
<td>Solomon et al. (2015)</td>
<td>-4.9 %</td>
<td></td>
<td>-2.0 %</td>
</tr>
<tr>
<td>Solomon et al. (2018a)</td>
<td>-3.9 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solomon et al. (2019b)</td>
<td></td>
<td></td>
<td>-1.7 %</td>
</tr>
</tbody>
</table>

*at 200 km altitude
Comparison of Density Trends at 400 km

This Work

Keating et al. [2000]
Marcos et al. [2005]
Emmert et al. [2008]
Saunders et al. [2011]
Qian et al. [2006]
Solomon et al. [2015]
“Warm Down, Cool Up”

(a) 1974, solar min
2003, solar min
1974, solar max
2003, solar max

(b) 2003–1974, solar min
2003–1974, solar max

(c) 1974
2003

(d) 1974
2003
Summary and Conclusions

• Observations and model simulations demonstrate that the upper atmosphere, particularly the thermosphere/ionosphere, is cooling and contracting in response to anthropogenic change, primarily increases in CO$_2$.

• There is considerable interannual variability in global mean annual mean temperature change, especially near the mesopause.

• Solar variability makes it challenging to quantify anthropogenic change above the stratopause, and to verify whether our models are calculating it correctly.

• The cooling of the upper atmosphere, while solar activity is decreasing, demonstrates that the warming of the lower atmosphere is not caused by our star, but by ourselves.

For more information, see:


n.b.: also available from the authors at http://download.hao.ucar.edu/pub/stans/papers
Workshop on Wednesday

CEDAR and Climate Change

10:00 – 12:00

Zia/Eldorado

Workshop Description

The Intergovernmental Panel on Climate Change 1.5 degree report (https://www.ipcc.ch/sr15/) released in October 2018 concluded risks of dire consequences of climate change and that the next decade is critical for transformational change to achieve deep reductions in greenhouse gas emissions to avoid the most serious impacts. This workshop will provide a forum for discussion about ways that the CEDAR community might contribute to global efforts to address climate change. Such efforts could include whole atmosphere studies of climate change processes; identifying aeronomy data sets and techniques that can also provide tropospheric information; continued work to reduce uncertainties in observations to facilitate their use for longer-term comparisons; and ways that the CEDAR community is or could potentially contribute to national and international climate assessment processes. We also welcome presentations relating to communicating climate science to the public.