Impact of Solar Variability on Ozone and Temperature

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How do stratospheric ozone and temperature respond to the solar cycle?

• **Direct heating**
  – $hv + O_2, O_3 \rightarrow T$ increase
  – speeds ozone loss reactions $\rightarrow O_3$ decrease

• **Photolysis**
  – $hv + O_2$ produces $O_3 \rightarrow O_3$ increase
  – More $O_3$, more heating $\rightarrow T$ increase

Same direction for temperature
Opposite direction for ozone
Chemistry Transport Model

- Sun
- Photolysis
- Chemical Reaction Coefficients
- Radiation (Temperature)
- Dynamics (Meteorology)
- Chemistry (Constituents)
- Surface Sources
Atmospheric General Circulation Model

- Sun
  - heating
  - Radiation (Temperature)
    - Dynamics (Meteorology)
    - Chemistry (Constituents)
    - Surface Energy Balance
What is a chemistry/climate model?

A chemistry climate model is a general circulation model of the atmosphere in which the concentrations of radiatively-active gases are self-consistently calculated and used to determine atmospheric heating and cooling rates.

Chemistry Climate Model

- O₃, CO₂, H₂O, CH₄, N₂O, CFCs

Diagram:
- Sun
- Radiation (Temperature)
  - Heating
  - Photolysis
  - Chemical Reaction Coefficients
- Dynamics (Meteorology)
- Chemistry (Constituents)
- Surface Energy Balance
- Surface Sources
Evaluation of Chemistry Climate Models – SPARC initiative called CCMVal

Published papers in JGR, Eyring et al. (2006, 2007), Waugh and Eyring (2008)

Range of all models (18)

Models are tested in CCMVal for their quality in reproducing observed processes, e.g. isolation of polar vortex, speed of residual circulation, tropical/mid-latitude mixing. The selection of “best” models can then be tested for how well they reproduce long-term trends of last 3 decades.

Range of models that were judged to have best process representation (3,6)
Estimates of Solar Impact on Ozone and Temperature in the Stratosphere using GEOS CCM

Used Lean estimates of spectral variation from solar max to min
Latitude dependence of solar effect on total column ozone

Note strong interannual variability in Max – Min in high latitudes
Global Average Response to Solar Variation

Ozone response to heating is much smaller than response to photolysis and in opposite direction.

Temperature response to photolysis is comparable to and is in same direction as response to heating.
Stratospheric temperature response to 11-yr solar cycle forcing

GISS Model E
SMax-SMin TSI*
1.2 W/m²
Cahalan et al. [in press 2010]

GEOS CCM-StratChem
Lean SSI
SMax-SMin TSI*
Scaled to 1.2 W/m²
Stolarski & Swartz [this work]

*TSI for 200-10,000 nm
Solar Cycle in Quasi-Global (60S-60N) Total Ozone

Blue is model sensitivity calculated from max/min simulations scaled to F10.7

Red is F10.7 term derived from time-series analysis of merged ozone data.
Construction of Merged Ozone Data Sets
### Version 8 Merged Ozone Data Sets

**Total Ozone Revision 05**  
**Profile Ozone Revision 01**  

*DATA THROUGH: DEC 2009*  
*LAST MODIFIED: 18 MAR 2010*

<table>
<thead>
<tr>
<th>Total Ozone</th>
<th>5° ZONAL MEAN</th>
<th>5° x 10° GRID MEAN</th>
<th>10° x 30° GRID MEAN</th>
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<tbody>
<tr>
<td>V8 Zonal Total Ozone</td>
<td>V8 Gridded Total Ozone</td>
<td>V8 Gridded Total Ozone</td>
<td></td>
</tr>
<tr>
<td>Revision 1 Profile Ozone Layer Amounts (DU)</td>
<td>V8 Zonal Profile Ozone</td>
<td></td>
<td>V8 Gridded Profile Ozone (not yet available)</td>
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<tr>
<td>Revision 1 Profile Ozone Volume Mixing Ratio (PPMV)</td>
<td>V8 Zonal Profile Ozone</td>
<td></td>
<td>V8 Gridded Profile Ozone (not yet available)</td>
</tr>
<tr>
<td><strong>Revision 01 Profile MOD does not yet include data below 64hPa or above 1.0hPa. Below we include the extended Revision 00 Profile MOD (no adjustments) with data at all levels.</strong></td>
<td></td>
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<tr>
<td>Revision 0 Profile Ozone Layer Amounts (DU)</td>
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</table>

http://acdb-ext.gsfc.nasa.gov/Data_services/merged/
Ozone Profiles from Backscatter Ultraviolet Data

Upper stratospheric data from 4 satellites

SBUV instruments provide longest data set with near-global coverage

Pressure = 3 hPa
Latitude = 20-25 S

Major issue is establishing relative calibration when there is no overlap of instruments in good parts of drifting orbits; as in 1997 with NOAA 9 and NOAA 11.
Total column ozone data set from TOMS and SBUV backscatter UV instruments
Removing Natural Variability from the Ozone Record

- Chlorine impact should have leveled off in last decade

- First solar cycle in 30-year record without major volcanic eruption

- Should also be a slow climate-change impact on stratospheric ozone that is difficult to separate from other variations
How much ozone will there be in the post-CFC era?

We use our chemistry climate models (CCMs) to try to answer this question.

Upper stratospheric ozone increases because of GHG cooling.

Tropical ozone won’t change at all.

$X_{14}$ decades $\approx$ 30 more DU in 2100 compared to 1960.

Lower stratospheric ozone decreases in tropics and increases at high latitudes: signature of circulation change.
Deducing 11-year solar cycle effects from time-series analysis: the importance of time lags

Computation of time delay from Goddard 2D CTM for solar cycle effect (Fleming and Jackman). Model was run with and without solar cycle in time-dependent mode.
Time-series regression analysis for solar cycle from model simulation with all perturbations

Ignoring time delays can modify magnitude of signal and introduce false signals -- even without interannual variability of real atmosphere (or CCM)
Summary and Conclusions

• Ozone is no longer decreasing in the stratosphere

• Attribution of this leveling off to decrease of chlorine containing compounds is complicated by several factors
  – Underlying changes in climate/temperature
  – Phase and importance of solar cycle
  – Natural, decadal scale variability

• Solar cycle impact on ozone and temperature depend on both direct heating and photolysis
  – Additive and approximately equal for temperature
  – Opposite direction for ozone dominated by photolysis