Effect of the 11-Year Solar Cycle on Stratospheric Temperatures

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Stratospheric Temperature Trends

- SSU – Stratospheric Sounding Unit
- MSU – Microwave Sounding Unit

Overall: Negative Trend

Models
- CO$_2$, O$_3$, H$_2$O

Variability
- Volcanoes
  - Stepping
- Solar

-0.5K in 5 years!!

WMO, Scientific assessment of ozone depletion: 2002
How can the solar cycle influence the stratosphere?

- Large percentage effect in UV
- Effects shortwave heating \((O_2, O_3)\)
- Change in UV has effect on \(O_3\) concentrations
- This in turn has effect on heating
- Magnitude and distribution of change varies between studies

Percentage change in spectral flux from solar min to max [data: Lean et al, 1997].

Percentage change in ozone from solar min to max determined from observations (annual mean) [data: SAGE satellite, Randel, 2005].
Approach

• Determine radiative component of solar cycle effect

  • The model [Forster and Shine, 1997]:
    • Narrow band radiation code
    • Fixed Dynamical Heating (FDH)

• This has been used instead of a General Circulation Model (GCM) for three main reasons:

  i. The radiative response can be isolated.
  iii. High spectral resolution radiative calculations can be performed.
  v. A large number of separate calculations can be run quickly.
Spectral Sensitivity

Temperature change due to the spectrally resolved irradiance changes

Using total UV changes
Mg II line removed
Mg II line changes only

Experiment Setup:
October at Equator

(from Lean et al. 1997)

To assess the importance of the Mg II line, three experiments were conducted with the FDH model:

i. Using actual solar cycle UV change (Black).

ii. Same as i. but without Mg II line (Blue).

iii. Just Mg II line change (Red).

The Mg II line has moderate importance to total solar change. ~1/6 of total effect at 1 mbar.

ii. and iii. sum linearly to reproduce i.
A solar maximum minus minimum experiment

- Irradiance changes only
- Ozone changes only
- Combining the two
- Compare to other studies
Temperature response implementing solar max minus min irradiance changes only
Shibata and Kodera, 2004

Using GISS ozone

Reading FDH response using SAGE I/II ozone

Randel (2005) SAGE I/II ozone

Ozone changes max – min %

Resulting FDH temperature changes max – min [ K ]

Also:
Comparison to other results

GISS – Shindell et al. (1999)

Approximate height [ km ]

Latitude

Pressure [ mbar ]
Ozone + Irradiance response

Reading FDH response (SAGE ozone changes + UV irradiance changes)

Also:
Comparison to other results

Applying Satellite weighting functions

Peak lowered in magnitude and height
Ozone effect vs. irradiance effect

Bold line “50/50”.

Dotted lines “irradiance wins”.

Solid lines “ozone wins”

Equal effect at equatorial stratopause

Ozone effect aided by longwave component at lower levels
Conclusions

- Fine Spectral features (~few nm) can cause a temperature effect (e.g. Mg II line)
- Solar cycle ozone changes required to influence solar induced temperature changes in lower stratosphere
- Important to get the ozone distribution correct
- Hints that the importance of dynamics is to get the ozone change distribution right, then radiative processes act upon it.
- Next steps: Perform perpetual minimum and perpetual maximum (~20 years each) using a GCM
- Perform time-varying (over satellite era) experiments
  - Using 1nm resolved spectral changes (Lean 2005)
  - Using SAGE ozone changes scaled to solar 10.7cm flux
Approach

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\[
\frac{\partial T}{\partial t} = Q(T) + D = 0
\]

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Rough slide

Radiative forcing
Results from idealised ozone change experiment

Change in radiative heating (max minus min) [ K / day ]

“Minimum” = Climatology – 0.5 x change

“Maximum” = Climatology + 0.5 x change
Temperature change
(max minus min)
[K]
(Oct)
Rough slide
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Degraded result to SSU/MSU channels
Rough slide
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First look at time variation