The atmospheric response to solar irradiance variations: Simulations with HAMMONIA

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Outline

• HAMMONIA - Model description
  - Implementation of solar heating and photodissociation

• Simulation Results
  - The atmospheric response to the 27-day variation
  - The atmospheric response to the 11-year solar cycle

• Outlook – SSI data needs
HAMMONIA – Hamburg Model of the Neutral and Ionized Atmosphere
HAMMONIA – a member of the ECHAM family

Solar Heating (near UV, vis. & near IR)
Solar Heating (SRB&C, Ly-α, EUV)
IR Cooling
IR Cooling (non-LTE)
Chemical heating
Surface Fluxes
Clouds & Convection
Turbulent Diffusion
Gravity Wave Drag
Neutral Gas Phase Chemistry (MOZART3)

H. Schmidt et al., ESSL workshop, Boulder, Jun. 2006
Acknowledgements

People at (or formerly at) MPI-Met:
• M. Charron, T. Diehl, E. Manzini, and E. Roeckner and the ECHAM-team

People who contributed to the model development outside MPI-Met:
• V. Fomichev\textsuperscript{1}, D. Kinnison\textsuperscript{2}, and S. Walters\textsuperscript{2}

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\textsuperscript{2} NCAR, Boulder, USA

• J. Lean (Naval Res. Lab., Washington, USA) provided the solar irradiance spectra
• D. Marsh (NCAR) helped in the model evaluation with SABER data
• M. Zecha and P. Hoffmann (IAP Kühlungsborn) for model evaluation with ground-based observations
• Computations were made at the DKRZ (German climate computing centre)
• The work was supported by the BMBF (German ministry for education and science)
### Solar heating and photochemistry in HAMMONIA

<table>
<thead>
<tr>
<th>Spectral range (nm)</th>
<th>Number of bands</th>
<th>Heating</th>
<th>Photodissociation / -ionization</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000 – (680,250)</td>
<td>3,4</td>
<td>Fouquart &amp; Bonnel (CAP, 1980); scaled with TSI; O3, H2O, aerosols, CO2</td>
<td>-</td>
</tr>
<tr>
<td>4300 - 1050</td>
<td>1</td>
<td>Ogibalov &amp; Fomichev (ASR, 2003); CO2 near-IR bands; table approach</td>
<td>-</td>
</tr>
<tr>
<td>(735,680,250) - 200</td>
<td>122,117,20</td>
<td>TUV (from MOZART/WACCM); table approach; only O3 and O2 used for heating</td>
<td>+</td>
</tr>
<tr>
<td>200 - 120</td>
<td>34</td>
<td>TUV (from MOZART/WACCM); explicit approach; only O3 and O2 used for heating</td>
<td>+</td>
</tr>
<tr>
<td>105 – 5 (old)</td>
<td>37</td>
<td>EUVAC (Richards et al., JGR, 1994); uses F10.7 as proxy</td>
<td>-</td>
</tr>
<tr>
<td>105 – 0.05 (new)</td>
<td>22</td>
<td>EUVAC modified using TIMED/SEE observations (Solomon&amp;Qian, JGR, 2005)</td>
<td>+</td>
</tr>
</tbody>
</table>
Solar spectral irradiance data used in HAMMONIA simulations

All data provided by J. Lean (Naval Res. Lab., Washington, USA)

Time slice experiments, 11-year solar cycle:
Solar max: Nov. 1989 (F10.7=235.1)
Solar min: Sep. 1986 (F10.7=68.7)
Spectral resolution: 1 nm, interpolated to the respective bins from 120 to 735 nm

27-day solar rotational cycle experiments:
Spectral resolution: 1 nm
Temporal resolution: 1 day
Time period available: 1990 - 2000
Time period chosen: Jan-Jun 1990
Solar 11-year cycle variability
Solar spectral irradiance data used in HAMMONIA simulations

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27-day solar rotational cycle experiments:
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Time period available: 1990 - 2000
Time period chosen: Jan-Jun 1990
Solar rotational variability

Power Spectrum, 205 nm radiation

Amplitude of Variability, Jan-Jun 1990

27 days

13.5 days
The solar rotational cycle
The 27-day solar signal
(analysed done by A. Gruzdev,
Obukhov Institute for Atmospheric
Physics, Moscow)

Correlation between normalized O3 variations (smoothed) and 27-day variations in solar irradiance within 20S-20N experiment 067 - 27-day forcing, 1990-1994

Whole period

Correlation between normalized O3 variations (smoothed) and 27-day variations in solar irradiance within 20S-20N experiment 068 - no forcing, 1990-1994

Whole period
Spectral analysis of ozone variations at 50N

with 27-day forcing

35 km

(c)

Period (day)

50

40

30

20

10

(d)

Period (day)

50

40

30

20

10

100 km

(e)

Period (day)

50

40

30

20

10

(f)

Period (day)

50

40

30

20

10

Year of simulation

2.0

3.0

4.0

5.0

Year of simulation

2.0

3.0

4.0

5.0

no forcing
The 11-year solar cycle
The solar cycle response in HAMMONIA-67
annual mean, O3 and T

Schmidt et al., J. Climate, 2006
(both papers available on H. Schmidt’s homepage, http://www.mpimet.mpg.de/...)

H. Schmidt et al., ESSL workshop, Boulder, Jun. 2006
Solar cycle effect on July chemistry
Solar cycle effect on wintertime zonal mean zonal wind (solar max-solar min) - Northern hemisphere

NCEP analyses, (Kodera & Kuroda, JGR, 2002; Matthes et al., JGR, 2004)
The QBO simulated by MA-ECHAM5

Observations: $u$ at Singapore (m/s)

MA-ECHAM5: $u$ at Singapore (m/s)

(Giorgetta et al., GRL, 2002, J. Climate, 2006)
The solar cycle response in HAMMONIA-119 annual mean, $T \, [K]$

(preliminary results from 10 years of simulation)

More results: Aug 21, 3:30 pm, NCAR, Foothills Lab
Outlook – SSI data needs

- Highly resolved spectral data are needed for 120 to about 700 nm, shorter wavelengths will be simulated using F10.7 as a proxy, longer wavelengths are represented in large bins.
- Spectral (1 nm) and temporal (1 day) resolution of data as provided by J. Lean are sufficient for most applications.
- For transient simulations of the recent past (~100 years), data for several solar cycles would be needed → we have to rely on models.
- It might be interesting to have data with high temporal resolution (10 min ?) for solar proton events.
- How accurate are irradiance data?
The End
Conclusions – 27-day variation

- Sensitivities and phases of ozone and temperature responses are in general close to observations.
- The atmospheric response to solar variations is strongly intermittent.
- Internal atmospheric variations with periods close to 27 days may be misinterpreted as solar signals.
- The solar response may interact with internal variations.
- The response in ozone is non-linear at certain altitudes.
- A significant wind response has not been detected in our analysis.
Conclusions – 11-year cycle

• 11-year cycle effects in the MLT are strong.
• The magnitude of the stratospheric ozone and temperature response is in agreement with observations. – How sure are we about the response in the real atmosphere?
• The solar signal in stratospheric model winds is not robust. – How robust is the signal in the real atmosphere?
Sensitivity of the 27-day ozone and temperature responses (%/%)

(a) Ozone

(b) Temperature
Phases of the 27-day ozone and temperature responses
The solar cycle effect on the diurnal variation of ozone at the mesopause

Ozone, 2.e−3 hPa, solar min, July

delta O3 [%], 2.e−3 hPa, solar max − min, July
Solar cycle effect on wintertime zonal mean zonal wind (solar max-solar min) - Northern hemisphere

NCEP analyses,
(Matthes et al., JGR, 2004)

old simulations
HAMMONIA

10 years
HAMMONIA – vertical grids

old (67 layer)

\[ z_f \text{ and } dz \text{ of L67-H, } ps = 1000,750,500 \text{ hPa} \]

new (119 layer)

\[ z_f \text{ and } dz \text{ of L119-H, } ps = 1000,750,500 \text{ hPa} \]
The QBO simulated in HAMMONIA-119 (preliminary results from 10 years of simulation)

- solar min
- solar max
- solar max - min
Spectral analysis of seasonal ozone variations at 50N

(c) winter (DJF)

(d) summer (JJA)
27-day Variation Experiments - Setup

Two simulations over 5 years each:

a) forced by mean solar irradiance as for January to June 1990
b) as in a) but with an additional 27-day variation of solar irradiance

- irradiance variation is assumed to be sinusoidal and have a period of exactly 27 days
- irradiance depending on wavelength (1nm resolution, see Lean et al., JGR, 1997) for $\lambda>120$nm has been analysed spectrally for Jan-Jun 1990
- the analysed amplitude for the 27-day period was used as amplitude of our artificial forcing
- EUV is modulated using F10.7 as proxy (Richards et al., JGR, 1994)
- SSTs fixed to climatological values
- compound concentrations at the surface are fixed to climatological values
Sensitivity of the 27-day ozone response (%,%)
27-day forcing

winter (DJF)

summer (DJF)

Sensitivity of the 27-day temperature response (K/%)
Sensitivity of 27-day trace gas responses (%/%)
Sensitivity of the 27-day trace gas responses (%/%)