The solar cycle effect in the MLT region
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Simulations with HAMMONIA

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Variability of solar UV irradiance as given by UARS / SOLSTICE

Observations of solar cycle signals in the MLT

HAMMONIA – model description

Solar cycle (and other) signals in simulations of the recent past (1960-2006)
  - What is the simulated response of the MLT to different forcing types (natural vs. anthropogenic)?
  - How representative are short observational time series?
  - Where does the signal in the MLT originate (local radiative vs. remote dynamic)?

Summary / Conclusions
Solar Cycle in Polar Mesospheric Clouds (aka NLCs)

(source: Wikipedia)

(DeLand et al., JGR, 2007)
Solar cycle effect on temperature simulation vs. observations

**delta T [K], annual zonal mean, (solar max – min)**

Numbers: observations as reviewed by Beig et al., Rev. Geophys., 2003; Color shading: simulated by HAMMONIA, Schmidt et al., 2006

- b: Reisin & Scheer, Ph. Ch. Earth, 2002, OH, O2
- e: Lowe, workshop paper, 2002, OH
- f: Keckhut et al., JGR, 1995, lidar
- g: Semenov, Ph. Ch. Earth, 2000, OH
- i: Espy & Stegmann, Ph. Ch. Earth, 2002, OH
- j: Luebken, GRL, 2000, rockets
- k: Sigernes et al., JGR, 2003, OH

#: zero or at least no significant trend
Temperatures observed by TIMED/SABER

(Figure courtesy from Sam Yee, APL/JHU)
Temperature anomalies (deseasonalized) above Fort Collins, CO (41N)

(She et al., JASTP, 2009)
The solar signal above Fort Collins, CO (41N)

(She et al., JASTP, 2009)
Temperature trends above Fort Collins, CO (41N)
Pinatubo temperature signal above Fort Collins, CO (41N)

(She et al., JASTP, 2009)
Hamburg Model of the Neutral and Ionized Atmosphere
HAMMONIA – Hamburg Model of the Neutral and Ionized Atmosphere

Simulations performed at T31 with 119 vertical layers
Equatorial zonal wind (m/s) in model versions of different vertical resolution

67 layers
strat. resolution: ~ 2000 m

119 layers
strat. resolution: ~ 800 m

(Pena-Ortiz, Schmidt, et al., submitted to JGR)
CCMVAL Ref1b experiment

- Simulation of the recent past (1960-2006)
- Observed SSTs
- Chemical lower boundary: observed GHG concentrations, observed CFCs, further trace gases from RETRO simulation
- Observed / reconstructed solar radiation
- Prescribed heating/cooling from volcanic aerosol
- Internally generated (or nudged) QBO

Description of CCMVAL2 simulations:
Eyring et al., SPARC Newsletter, 2008

SPARC / CCMVAL report published in April 2010:
HAMMONIA simulations

2 simulations with internally generated QBO

1 simulations with “nudged” QBO

Solar cycle QBO interactions:
Labitzke, GRL, 1987;
Labitzke and van Loon, 1988;
⋯
Schmidt et al., JGR, 2010
T(K), SABER vs. HAMMONIA

(Figure courtesy from Sam Yee, APL/JHU)
$T_{\text{anom}}(t) = c_{\text{trend}} \cdot t + c_{\text{solar}} \cdot F107(t) + c_{\text{volc}} \cdot SAD(t) + c_{\text{enso}} \cdot MEI(t) + c_{\text{qbo28}} \cdot u28(t) + c_{\text{qbo10}} \cdot u10(t)$
Temperature anomalies from CCMVAL Ref1b experiment.
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Temperature anomalies from CCMVAL Ref1b experiment
Δ T (solar variability), annual mean, 1960-2006

solar (K / 100sfu), ANN

~110km
~80km

pressure [hpa]

90S 60S 30S 30N 60N 90N

latitude

0.2 0.2 0.2 0.5 0.5 0.2 0.2 0.5 0.5

1 2 1 2 5 10 20 50

5 3 3 5 10 20

1e-05
The solar signal above Fort Collins, CO (41N)

(She et al., JASTP, 2009)
Δ \( T \) (trend), annual mean, pressure vs. Altitude coordinates
Δ T, annual mean

Volcanic (K / Pin.), ANN

Enso (K / 4MEI), ANN

QBO (10hPa) (K / 40m/s), ANN

QBO (28hPa) (K / 30m/s), ANN
Δ T (solar variability), annual mean

Free QBO

Nudged QBO

Free QBO
Δ T (solar variability), January

free QBO

nudged QBO

free QBO
NB: Simulated variability in the MLT may be underestimated because of missing variability from geomagnetic and solar particles.
Solar signal in different solar cycles and experiments at 0N and 80N

1960-2006
1965-1975: cycle 20
1976-1985: cycle 21
1986-1995: cycle 22
1996-2006: cycle 23
Standard deviation in estimated solar signals from 12 simulated solar cycles

Standard deviation (K/100sfu)
The importance of dynamical coupling for the solar signal around the mesopause

Polar winter stratosphere and polar summer mesopause region are dynamically linked. (e.g. Becker and Schmitz, 2003; Becker et al., 2004; Becker and Fritts, 2006; Schmidt et al., 2006; Karlsson et al., 2007, 2009)

(Karlsson et al., GRL, 2007)
Interhemispheric temperature correlations, CMAM vs. HAMMONIA (Karlsson et al., JASTP, 2009)

Fig. 1. Correlation between the CMAM monthly and zonal mean temperature anomaly in the summer mesopause region (from $0.3 \times 10^{-2}$ to $0.3 \times 10^{-4}$ hPa and latitudes poleward of 50°) and the monthly and zonal mean temperature anomalies in the rest of the atmosphere for (a) January and (b) July. For consistency with the observations shown in Fig. 2(b), the temperature anomalies in the summer mesopause region have been multiplied by $-1$ before computing the correlation. White lines denote the 95% significance level. The black lines show the climatological 130 and 150K temperature contours, which indicate the location of the polar summer mesopause. Approximate altitude (based on log-pressure with a scale height of 7 km) is indicated. Note that the model domain extends much higher than the vertical range of the plots.

Karlsson et al., JASTP, 2009
Simulated correlation
NH winter stratosphere - SH summer mesopause

January

\[ Y = 0.16 \times x, \quad r=0.42 \]
Simulated correlation
SH winter stratosphere - NH summer mesopause

July

\[ Y = 3.56 \times x, \quad r=0.53 \]
Mesopause responses simulated by HAMMONIA:

- Solar forcing: ~3K/100sfu
- Trend: insignificant at the mesopause; up to -1.5K/decade in the lower mesosphere
- ENSO, QBO, volcanoes have locally significant effects

Available time series are often too short for an unambiguous attribution of observed signals. (How strong is the volcanic influence in the mesopause region?)

However, in the low to mid-latitude MLT, global observations over one solar cycle should provide a good estimation of the solar UV influence.

The MLT high latitudes are strongly influenced by the variability of the stratosphere.

Other types of solar input have a temperature effect on the MLT: 27-day variability (Gruzdev et al., ACP, 2009); EPP
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