Contribution from GOME on the linkage between solar activity and climate

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with contributions from:

GOME1 Ten Year Anniversary Workshop, Noordwijk, 20th April 2005
Overview

- Dynamical and chemical contribution to ozone variability at middle and high latitudes.

  ➔ What about *ozone-climate interaction*?

- Solar activity and northern hemispheric ozone trends.

  ➔ What’s all about „ozone recovery“?

GOME data used (scientific data products):

- WFDOAS V1 total ozone (Coldewey et al., 2005, Weber et al. 2004)
- OCIO vertical columns (Wittrock et al. 1999)
- FURM V5 ozone profiles (Hoogen et al. 1999, Bracher et al., 2004)
- NNORSY ozone profiles (Müller et al. 2003)
- Mg II index solar activity proxy V2.1 (Weber et al., 1998, Weber 1999)
High inter-annual ozone variability in winter/spring NH

- **Cold** Arctic winters with low ozone:

- **Warm** Arctic winters with high ozone
Height resolved ozone from GOME

FURM V5

1998/03/13 1998/03/13 1998/03/13

8-15 km 15-23 km 23-30 km

Eichmann et al. 1999
Height resolved ozone from GOME

1998/03/13

8-15 km

15-23 km

23-30 km

ozone within polar vortex „chemistry & dynamics“

ozone mini holes „dynamics: lifted tropopause and subtropical streamer“

Eichmann et al. 1999
GOME and ozone sondes in NH polar vortex

- Chemical ozone loss: 110 DU (~50%)
- 400-600 K (16-24 km)

Eichmann et al. 2002
Polar stratospheric clouds (PSC) activate chlorine (see OCIO from GOME) and are responsible for severe chemical ozone loss. Note: inter-annual variability in PSCs (stratospheric temperatures), OCIO, and chemical ozone loss.

Note: In winter 2004/2005 ozone loss is expected to be comparable to winter 1999/2000 with ~50% chemical ozone loss.
Annual cycle in total ozone
Annual cycle in total ozone

GOME TOZ [1995-2003]

Latitude

Photochem. decay

Interannual variability
Winter/spring ozone

Photochem. decay
- NH ozone anomaly in spring (high or low ozone) persists into summer (Shepherd and Fioletov 2003)
- In SH spring ozone is lower than in summer/fall (severe chemical ozone loss in Antarctic ozone hole). Exception: ozone hole anomaly in 2002. Note: October 2003 and 2004 business as usual.
EP (Heat) Flux and Brewer-Dobson Circulation: ozone-climate interaction

NNORSY (Müller et al., 2003)
EP (Heat) Flux and Brewer-Dobson Circulation: ozone-climate interaction

**Diagram Description**

- **EP (Heat) Flux** and **Planetary scale wave driving**
- Energy and momentum transfer
- "Extratropical pump"

**Residual/meridional circulation**

**Brewer-Dobson circulation (ozone)**

**Ozone & T variability chemistry/transport**

**Factors**

- Sea surface temperature
- Orography (mountain)
- Tropospheric forcing

**References**

NNORSY (Müller et al., 2003)
EP (Heat) Flux and Brewer-Dobson circulation: ozone-climate interaction

Meridional circulation ~2-4 y

ozone production

cold/warm winters

polar ozone loss / transport

Ozone & T variability chemistry/transport

sea surface temperature, orography (mountain) tropospheric forcing

EP (heat) flux/ Planetary scale wave driving energy- and momentum transfer „extratropical pump“

Residual/meridional circulation Brewer-Dobson circulation (ozone)
Tropospheric forcing and spring/fall total ozone ratio

GOME spring/fall ozone ratio

- 50°-90°
- Sep over Mar (SH)
- Mar over Sep (NH)

winter heat flux

- 40°-70°
- 100 mbar
- Sep-Mar (SH: Mar-Sep) integrated and averaged

SH anomaly 2002

V3 WFDooas

Update from Weber et al. 2003
Tropospheric forcing and chlorine activation

- OCIO
  - BrO+ClO -> OCIO + O
  - Measured in twilight inside the polar vortex
  - Maximum vertical column at 90° solar zenith angle integrated over the winter
  - Below 92°SZA OCIO is a measure of chlorine activation

Update from Weber et al. 2003

- OCIO

High chlorine activation persisted during SH anomaly 2002

Longterm changes in planetary wave forcing related to a changing climate change modifies both ozone transport and chemistry
Mg II h and k emission is a suitable proxy for solar spectral variability in the UV and far UV down to 30 nm (Weber 1999, Viereck et al. 2001)
Solar Observations from GOME1

Composite Mg II index from GOME, SUSIM, and SBUV/NOA (Weber 1999, Viereck et al. 2004)

Composite Mg II index from GOME and SCIAMACHY (Skupin et al. 2004)
Long-term trend: SBUV & GOME NH total ozone

- Total ozone anomaly in NH from GOME and SBUV(2) from 1979-2003.
- Minimum in mid 90s and rapid increases since then (ozone recovery?)
- Modelling of ozone variability using explanatory variables (heat flux, solar variability, stratospheric aerosols, PSC volume, QBO)
- Note: differences between GOME and SBUV are larger after 2000 (GOME aging?). highlights importance of multiple satellite data sets!
Largest contribution to recent increases at NH mid- to high latitudes are due to solar variability (+10 DU) and heat flux (+20 DU)

Ozone recovery due to turn around in the estimated effective stratospheric chlorine (EESC) is only a few DU
Increasing planetary wave activity in NH?

Will the recent increase in planetary wave driving continue (as could be expected in a future climate, Schnadt et al., 2002, Butchart and Scaife, 2001) or is just part of decadal scale natural variability?

Still more years of data (SCIAMACHY, OMI, SBUV, GOME2) is needed to further improve on the understanding of coupling between solar and dynamics related influences on ozone trend and to confirm ozone recovery as expected from Montreal Protocol.

Dhomse et al., 2005
Happy Birthday GOME and ERS2!

...also thanks to the GOME Community for the success story!
Summary so far

- Close coupling between chemistry and dynamics (transport) related to planetary wave driving → heat/EP flux as dynamical proxy represents also chemical (dynamically induced) contribution

- EESC or linear terms in our regression model works equally well → we cannot uniquely attribute the observed „recovery“ to reversal of stratospheric chlorine loading, change in transport/circulation also contributes to the rapid increase

- Plan to extend analysis to height resolved ozone (SBUV, SAGE), stratospheric temperature, and water vapour (SAGE/HALOE) → Is there a dynamical contribution in upper stratospheric ozone „recovery“ (see Newchurch et al., 2003).

- What is the cause of the recent increase in EP/heat flux → climate change signal (persistent trend) or part of decadal scale variability?
Outlook for 2005/2006

- Extension of long-term trend analysis to ozone profiles, stratospheric temperature, and water vapour

- Adaptation of concepts of ozone–planetary wave driving relationship to CH4 and H2O using HALOE/SAGEII historical dataset.

- Water vapour retrieval from SCIAMACHY

- Tendencies in hemispheric MIPAS/SCIAMACHY CH4, H2O vapor, and methane data in relation to wave driving, investigate possible linkage of tropical lowermost stratospheric ascent rates (H2O) to mid-latitude wave activity
Temperature and zonal winds

Mean January T and zonal wind (1989–2001)

Mean July T and zonal wind (1989–2001)

Cold tropical lowermost stratosphere/tropopause

Cold polar vortex

Strong polar jet

Link between T variability in tropics to planetary wave driving (Yulaeva et al. 1994)

Link between planetary wave driving and Arctic T variability (Newmann et al. 2001)
Ten Year of GOME1 Total Ozone

Kontinuität der Nadirsäulenzeitserien mit SCIAMACHY ab 2002
Antarctic winter 2002

- September SH ozone for the first time above March (late fall value)
- Winter gain thru transport in ozone outweighs chemical ozone loss (August, September)
- Above average ozone in high latitudes starting in July lasting until December
Tropospheric forcing, ozone transport, and chlorine activation

- GOME Ozone ratio
  - 50°-90°
  - Sep over Mar ratio (SH)
  - Mar over Sep ratio (NH)

- GOME OClO
  - Maximum vertical column 90°SZA
  - Integrated over winter and divided by 365 days

- Winter heat flux (planetary wave activity)
  - 40°-70° mean at 100 hPa
  - Integrated from Sep to Mar and averaged

Update from Weber et al. 2003

Potential longterm changes in planetary wave forcing (residual circulation) modifies ozone transport and chemistry
First major stratospheric warming in SH

Polar vortex split on 25th September 2002

Record high absolute lower stratospheric heat flux on 20th/21st September (ERA40 1960-2002)

http://www.iup.uni-bremen.de/gome/SHevent