Dynamical chemical interactions in the stratosphere-chemistry and external forcings

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KODYACS

Kopplung von Dynamik und Atmosphärischer Chemie in der Stratosphäre

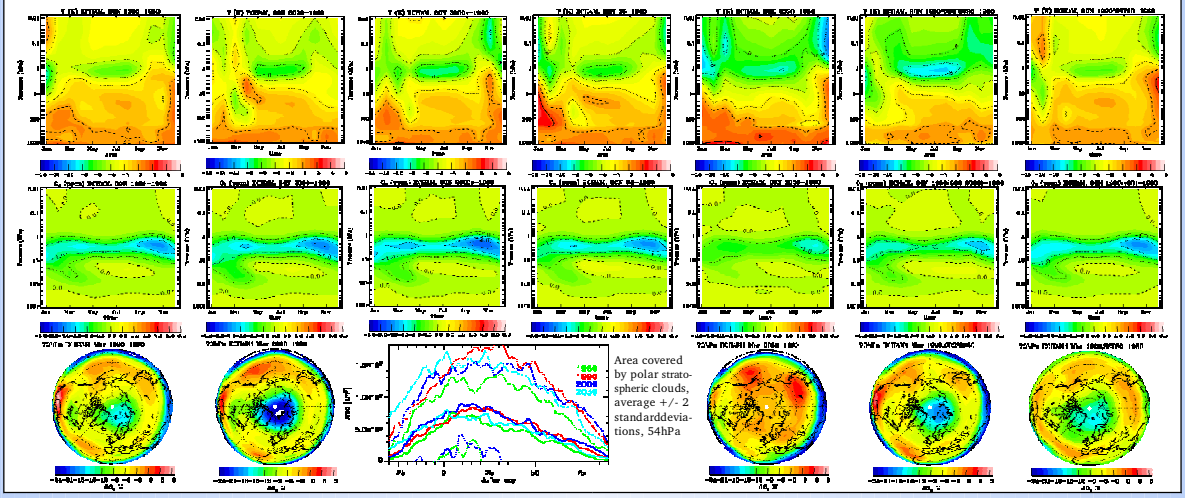
Abstract

The coupled chemistry-climate model MA-ECHAM/CHEM has been employed for 9 long-term simulations (2 decades each), i.e. so-called time-slice experiments with fixed boundary conditions, and a transient simulation which covers the time period between the years 1960 and 2000 in close cooperation with MPI-M (Hamburg).
The timeslice experiments for the early and late nineties have been compared with HALOE/UARS data (*Steil et al.*, 2003) and Berlin meteorological data. The model in general reproduces the observed mean state and interannual variability of temperature, ozone and watervapor in the stratosphere, including the polar regions. Changes in meteorology and chemistry from the sixties to the present are discussed in *Manzini et al.* (2003), including the aspect of the observed cooling of the Arctic lower stratosphere in the late nineties and the role of chemistry climate feedbacks. It is also shown that the mesosphere has an impact on the lower stratosphere via dynamics. Trends in ozone and temperature have been compared with observations compiled by DWD Hohenpeißenberg. Results are also compared in an international framework in *Austin et al.* (2003). The timeslice simulations include also a scenario for 2030 and sensitivity studies on the effect of sea surface temperature, chlorine and CO_2(presented at the SPARC conference at Elbsee, 2003, paper in preparation). The 11year solar cycle effect on ozone and dynamics is analysed by comparing timeslice runs with solar maximum and solar minimum radiative boundary conditions at the top (*Tourpali et al.*, 2003), showing similar patterns of wind changes in stratosphere and troposphere as observed. In all simulations photolysis at solar zenith angles exceeding 90 degrees is included as in *Lamago et al.* (2003),where together with DLR its importance for polar ozone chemistry is shown.
The transient simulation includes forcings by greenhouse gases and chemically active gases, observed sea surface temperature (SST), major volcanoes and solar cycle. The quasi-biannual oscillation of the zonal wind in the lower tropical stratosphere (QBO) is assimilated from observations (*Giorgetta*, MPI-M). We found that inclusion of QBO is essential for the vertical tracer transport into the middle and upper stratosphere. The ElNino/LaNina signal in SST has a clear impact on stratospheric water vapor and ozone via tropical tropopause temperature in agreement with observations. The volcanoes enhance stratospheric water vapor via heating of the 'cold point', causing more ozone destruction in the gas phase. The effect of the solar cycle is largest in the mesosphere. A detailed analysis of all these natural effects on ozone and temperature is in progress together with DWD Hohenpeißenberg and DLR. The chlorine increase due to the CFC-increase causes the development of the antarctic ozone hole in the early 80s and ozone depletion in the arctic lower stratosphere, as observed. Processes in the polar vortices will be compared with findings of our CTM-partners in KODYACS and with observations of AWI Postdam. Concerning analysis of transport from the stratosphere to the troposphere and its change, we use cosmogenic ^{14}CO as a diagnostic tool (*Jöckel et al.*, 2002).

The timeslice experiments: temperature and ozone changes in the Arctic

20 years monthly averages, 8 scenarios. (*together with MPI for Meteorology,Hamburg*)

1990 | 2000 | 2000, chlorine+10% | 2000, chlorine--10% | 2030 | 1990, CO2 of 2030 | 1990, SST of 1960

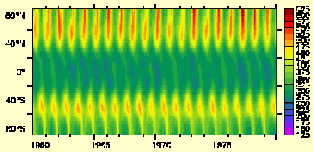


Area covered by polar stratospheric clouds, average +/- 2 standarddeviations, 54hPa

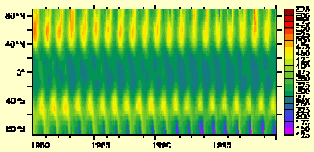
The model

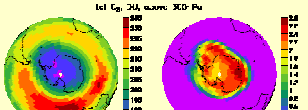
-Spectral GCM ECHAM4 (*Roeckner*), horizontal resolution T31 (3.75 degrees), surface to 80km.
-Spitfire advection (*Rasch*)
-Gravity wave scheme by *Manzini, McFarlane* (1998).
-Interactive chemistry based on the family concept using Ox, Nx, Clx, HOx (*Steil*).
-Heterogeneous chemistry on sulfate, ice and NAT particles.
-Interactive photolysis.
-10year average of seasonal sea surface tempatures using GISS/Hadley Center data (1951-1960, 1981-1990, 1989-1999) or the OPYC-model (2021-2030).

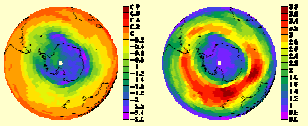
The transient simulation 1960-1999



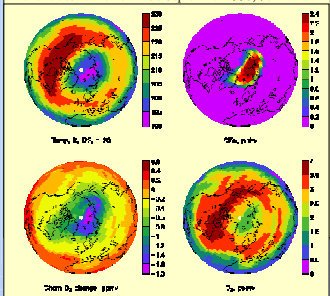
Total ozone, zonal averages of 10day-periods







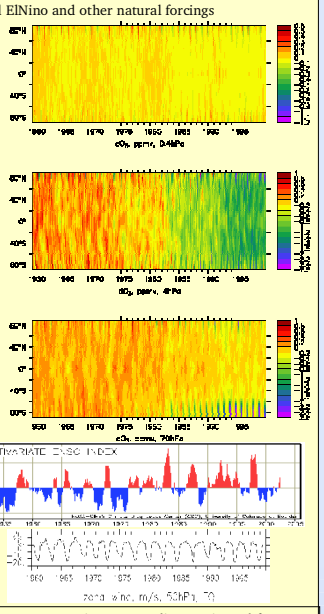
Temperature, reactive chlorine, ozone and chemical ozone destruction until 30 September 1998, 70hPa



Temperature, reactive chlorine, ozone and accumulated chemical ozone destruction until 30 March 1996, example for cold Arctic winter and spring, 70hPa.

Ozone and ElNino and other natural forcings

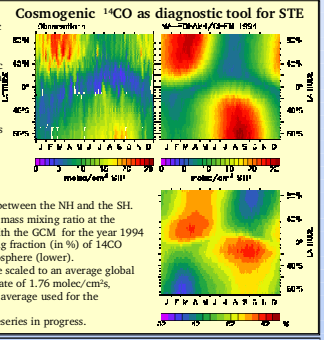
10 day average ozone anomalies, relative to the average seasonal cycle of the first 20 years in ppm.
In the mesosphere (upper panel) positive anomalies are clearly visible for *solar maximum* in the tropics, in the upper stratosphere (middle panel) the solar cycle causes a 'stepwise' decrease of ozone by chlorine. In the tropical lower stratosphere (lower panel) modulation of water vapor (see *KODYACS*-poster) by *ElNino* has the largest effect on ozone (negative, *LaNina* positive), followed by QBO (less ozone for east phase). In high latitudes heterogeneous depletion by chlorine. For a systematic analysis see poster by *Steinbrecht (DWD)*.



QBO

Cosmogenic ^{14}CO as diagnostic tool for STE

Left: Zonal average climatology of cosmogenic ^{14}CO compiled from total ^{14}CO observations at the surface level: The biogenic (secondary) ^{14}CO has been estimated and subtracted from the observations of atmospheric ^{14}CO. The cosmogenic contribution is in molec/cm³ STP, standardized to the average solar conditions during the period 1955 to 1988. The climatology shows a clear asymmetry between the NH and the SH.
Right: Zonal average ^{14}CO mass mixing ratio at the surface level calculated with the GCM for the year 1994 (upper), and corresponding fraction (in %) of 14CO originating from the stratosphere (lower).
The mass mixing ratios are scaled to an average global average ^{14}CO production rate of 1.76 molec/cm²s, corresponding to the time average used for the climatology (left).
Analysis of the whole timeseries in progress.



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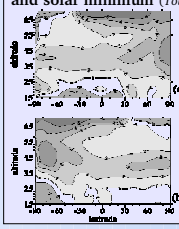
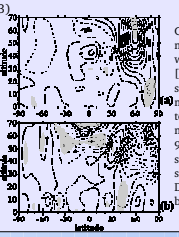
Steil et al., J. Geophys. Res., 108(D9), 4290, doi:10.1029/2002JD002971, 2003.
Manzini et al., J. Geophys. Res., 108(D14), 4429, doi:10.1029/2002JD002977, 2003.
Tourpali et al., Geophys. Res. Lett., 30(5), 1231, doi:10.1029/2002GL016650, 2003.
Lamago et al., Atmos. Chem. Phys., 3, 1981-1990, 2003.
Jöckel et al., J. Geophys. Res., 107(D20), 4446, doi:10.1029/2001JD001324, 2002.

The 11 year solar cycle, timeslice experiments for solar maximum and solar minimum (*Tourpali et al*, 2003)

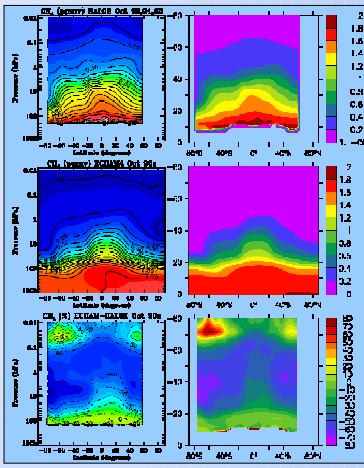


Percentage ozone changes at solar maximum compared to solar minimum, a) DJF (winter), b) JJA (summer)



Changes in mean zonal wind [m/sec], solar maximum to solar minimum, 95% significance shaded. a) December, b) February

The importance of QBO for tracer transport



Left: without QBO, comparison of timeslice experiment for early 90s with HALOE (*Steil et al*, 2003).
Right: with nudged QBO, comparison for the same years as the HALOE observations in the transient run.
Note the large reduction of percentage error in the lower panels.
QBO nudging causes also an improvement in NOy and is important for upward transport of CFCs.

Conclusions

- Only for the 2000 conditions the heating of the Arctic lower stratosphere in spring by increased descent (related to cooling of the upper stratosphere) is overcompensated by the effect of cooling by local ozone depletion.
- For artificially increased chlorine additional cooling of the upper stratosphere by gas phase ozone depletion causes enhanced heating by descent in the lower stratosphere, reducing PSCs and heterogeneous ozone depletion there.
- Increase of greenhouse gases like CO_2 without consistent ocean temperatures (tropospheric greenhouse effect mostly suppressed) causes a slower residual circulation which leads to a colder lower stratosphere in polar spring, an artifact which increases ozone depletion.
- **The QBO is essential for transport of tracers in the stratosphere.**
- Lower stratospheric ozone and water vapor show a clear signal of ElNino/LaNina.
- The 11 year solar cycle modulates ozone in the upper stratosphere and the mesosphere.
- The MAECHAM4/CHEM system with observed SST and nudged QBO reproduces a lot of observed features of ozone depletion in the polar lower stratosphere including interannual variability in both hemispheres and position of the vortices.
- Transport from stratosphere to troposphere overestimated in Southern Hemisphere.

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