KODYACS, interactions between ozone depletion, greenhouse gases and stratospheric dynamics based on studies with a chemical GCM and observations.

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Abstract

In preparation for a transient simulation we analysed 20-year simulations with a middle atmosphere chemistry climate model with fixed boundary conditions for about 1960, 1990 and 2000. We find that the model reproduces observed trends and variability in total ozone as observed by satellites and at different stations including Hohenpeissenberg. From the analysis of the dynamical response in the stratosphere and mesosphere and given that the tropospheric wave activity is comparable in the simulations, it is concluded that in the 2000 simulation the cooling in the lower stratosphere mainly involves radiative-chemical processes. These results support the interpretation that the observed extreme low temperature in March in the 1990s can arise solely from the radiative-chemical feedback. Gravity waves exert a negative feedback. In both the Arctic and Antarctic, the cooling from ozone depletion is found to affect the area covered with polar stratospheric clouds in spring, which is substantially increased from the 1960 to the 2000 simulations.

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MA-ECHAM4

[*Roeckner et al*, MPI-Rep.218, 1996; *Manzini et al*, 1997]
Middle Atmosphere version of the European Center model in Hamburg, spectral GCM with :

- horizontal resolution : T30; **time step : 15 min**
- vertical resolution : 39 levels up to 0.01 hPa (**80 km**), σ-p system
- prognostic variables : vorticity, divergence, surface pressure, temperature, water vapor, cloud water, chemical constituents
- gravity waves: *Manzini, McFarlane*, 1998, JGR.
- **Radiation, dynamics and chemistry fully interactive.**

Chemical scheme

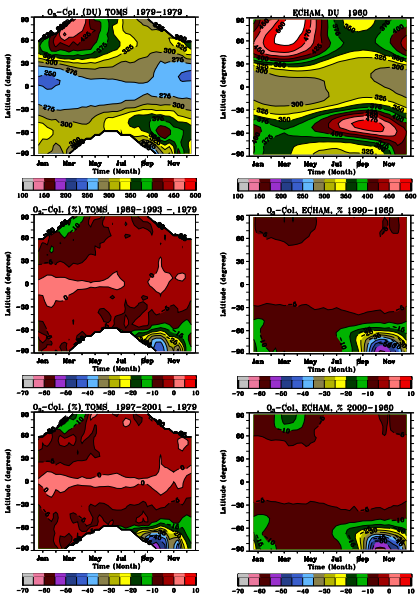
[*Steil et al*, 1998, Ann. Geophys.]

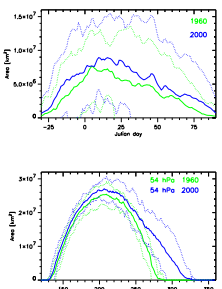
- Very efficient due to family-concept; **time step: 45 min**
- **Advection scheme Spitfire** (*Rasch, Lawrence*, **MPI-Rep.265, 1998**)
- horizontal resolution : $3.75^\circ \times 3.75^\circ$, Gaussian grid
- Advected long and medium lived gases: $N_2O, CH_4, H_2, CO, CH_3O_2H, H_2O_2, HCl, ClONO_2, F11, F12, CH_3Cl, CH_2Cl_2, CCl_4$
- Advected families and Polar Strat. Cloud particles: HNO_3 + Type I PSC (NAT : $HNO_3 \times 3H_2O$), Type II PSC (ice), ClO_X, NO_X, O_X
- 110 photochemical reactions, implicit + analytical solver
- interactive photolysis-rates, *Landgraf and Crutzen*, 1998, JAS
- PSCs and sedimentation of PSCs (solid only); direct use of GCM-temperatures

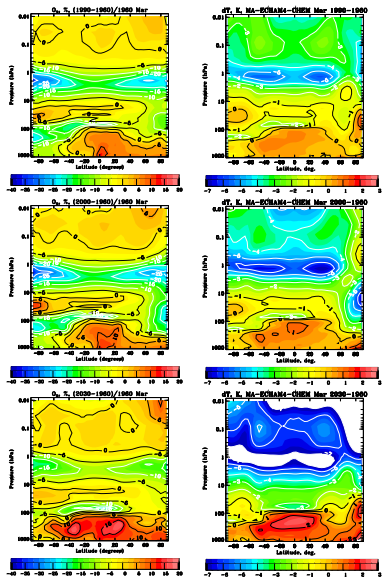
Lower boundary conditions of the 4 'time-slice' experiments

	1960 20 a	1990 20 a	2000 20 a	2030 20 a
Sea surface	GISS, HADLEY[1]			OPYC
temperature	1951 – 1960	1981 – 1990	1989 – 1999	model 2030
Volume mixing ratios	WMO 1999			
at surface				
CH_4	1.26 ppmv	1.69 ppmv	1.75 ppmv	1.90 ppmv
N_2O	295 ppbv	310 ppbv	320 ppbv	350 ppbv
organic chlorine	0.8 ppbv	3.4 ppbv	3.7 ppbv	2.7 ppbv
CO_2	317 ppmv	353 ppmv	372 ppmv	446 ppmv

1: Rayner et al, Hadley Center internal note 69, 1995.



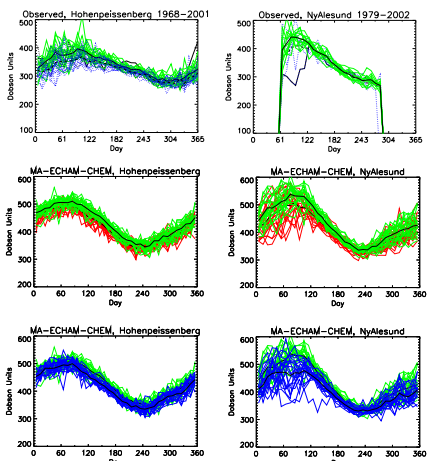




Monthly, zonal mean of total ozone from (left) TOMS observations and (right) the MA-ECHAM simulations. (top left) 1979 year from TOMS and (top right) 20-year average from the 1960 simulation (contour: 25 DU). Difference (middle left) between the 1989 to 1993 average and the 1979 year, from TOMS and (middle right) between the 20-year averages of the 1960 and 1990 simulations, 1990-1960. Difference (bottom left) between the 1997 to 2001 average and the 1979 year, from TOMS and (bottom right) between the 20-year averages of the 1960 and 2000 simulations, 2000-1960. The difference fields are in percent, the contour is 5%.

(top) Arctic and (bottom) Antarctic mean area covered with NAT-PSCs at the 54hPa level from (green) the 1960 simulation and (blue) the 2000 simulation. The dotted lines show the respective range covered by ± 2 standard deviations. Note the different x-y axis scaling.

Difference of (left) March zonal mean ozone and of (right) March zonal mean temperature: (top) between the 20-year averages of the 1960 and 1990 simulations, 1990-1960; (middle) between the 20-year averages of the 1960 and 2000 simulations, 2000-1960; (bottom) same but 2030-1960. Contours: (left) 5%; (right) 1 K.



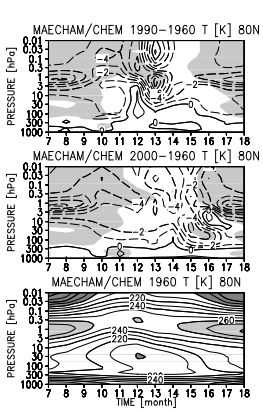
Observed (top) and calculated (middle and bottom) total ozone time series (10 day averages) at individual stations: left: Hohenpeißenberg (48N), right: NyAlesund (79N).

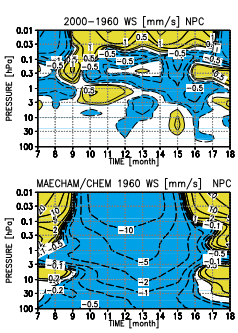
Top left: green 1968-1984, blue 1985-2001; top right: from TOMS satellite observations (no data in winter), green 1979-1989, blue 1997-2002.

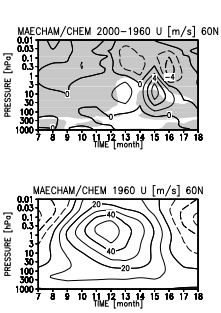
Middle and bottom panels: green 20 years of 1960 timeslice, red 1990 timeslice, blue 2000 timeslice. Black lines indicate average values, for the observations the dashed lines belong to the later period.

Conclusions

- Model captures characteristics of chlorine partitioning, Polar Stratospheric Clouds (PSCs), and ozone depletion in cold and warm springs compared to HALOE satellite data; total ozone high bias due to transport in winter.
- Area covered with PSCs increases significantly from 1960 to 2000 in both hemispheres in spring.
- Modelled past total ozone trends close to TOMS-observations and ground based observations, as well as interannual variability and seasonal cycle.
- Ozone recovery in 2030 due to chlorine decrease and heating of the lower stratosphere due to enhanced downward motion and enhanced heat transport by planetary waves.
- Interactive chemistry important in both hemispheres, dynamical effects on ozone most important in Arctic. In the Arctic gravity waves exert a negative feedback (remote, via the mesosphere) while planetary waves (related to zonal wind) a positive one (local).
- Model provides an excellent tool for predictions of chemistry-climate interactions.







Monthly, zonal mean zonal wind at 60° N. Difference (top) between the 20-year averages of the 1960 and 2000 simulations, 2000-1960. Contour: 2 ms^{-1}, light shade indicates a statistically significant difference at 95%, t-test. (bottom) 20-year averages from the 1960 simulation. Contour: 10 ms^{-1}. The time axis runs from July (month=7) to June (month=18).

Monthly, zonal mean temperature at 80 N. Difference (top) between the 20-year averages of the 1960 and 1990 simulations, 1990-1960; (middle) between the 20-year averages of the 1960 and 2000 simulations, 2000-1960. Contour: 1 K, light shade indicates a statistically significant difference at 95%, t-test. (Bottom) 20-year averages from the 1960 simulation. Contour: 10 K, light shade >260 K, dark shade <200 K. The time axis runs from July (month=7) to June (month=18).

Monthly mean of the residual vertical velocity, area weighted average poleward of 60° N. (top) Difference between the 20-year averages of the 1960 and 2000 simulations, 2000-1960. (bottom) 20-year averages from the 1960 simulation. Contours: ± 0.1, ± 0.2, ± 0.5, ± 1, ± 2, ± 5, ± 10, ± 20, ± 50 mms^{-1}; positive values are yellow and negative blue. The time axis runs from July (month=7) to June (month=18).

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