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Lagrangian CTM studies of
Future polar ozone loss

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Predictions of ozone recovery

The recovery of polar stratospheric ozone is uncertain and predicted between 2004 and 2019 by GCM simulations; ECHAM4.L39(DLR)/CHEM simulates Arctic ozone recovery in its "2015" timeslice experiment.

We employ the Chemical Lagrangian Model of the Stratosphere (CLaMS) based on cold-winter meteorological and chemical boundary conditions from 20-year E39C timeslice experiments, thus performing offline-CTM on coupled GCM calculations.

The GCM underestimates cold-winter ozone depletion compared to observations and to detailed CTM studies. Amongst other factors, bromine chemistry is not included in the GCM, which accounts for up to 20% of ozone depletion in CTM simulations; coarse model resolution does not resolve filaments and the isolation of the vortex, thus enhancing import of nitrogen species (NO_x+HNO_3) and hence deactivation of ClO_x.

We study the sensitivity of ozone loss estimates to mixing parameters, resolution and halogen chemistry. For ozone loss estimates, we use tracer-tracer correlations as well as passive ozone tracers to

- ➪ **determine a lower bound for the error in predicted ozone loss,**
- ➪ **quantify the transport of vortex-processed air into midlatitudes.**

A cold and stable vortex

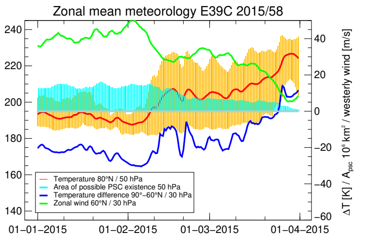

Figure 1. *Meteorological conditions in the "2015/58" simulated winter. Drawn in red is the zonally averaged temperature at 80°N, the orange shading shows the range of temperatures. For green, blue and cyan lines see legend.*

During the considered winter, the polar vortex is stable until the end of March. Throughout, conditions are cold enough for the formation of PSC. Severe denitrification (80% of NO_y, cmp. Figure 4) occurs during the first month.

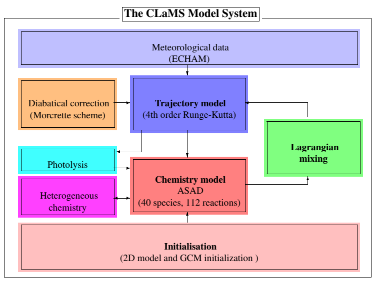

Figure 2. *Initial conditions are taken from E39C, initial bromine species from Mainz-2D. For threedimensional simulations (not shown), upper and lower boundaries are monthly mean Mainz-2D data.*

Horizontal resolution and mixing affect simulated ozone loss

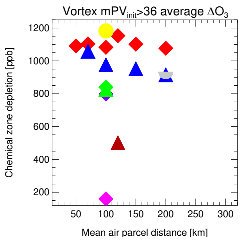

Figure 3. *90-day chemical ozone depletion derived from an inert tracer for different mixing parameters and horizontal air parcel distances.*

In weak-mixing scenarios (red diamonds) ozone loss is insensitive to the horizontal resolution for a stable vortex cold E39C "2015" winter. For moderate mixing (blue triangles) we find that simulated chemical ozone depletion is highly dependent on the horizontal resolution of the model. For a given resolution, vortex ozone loss decreases with mixing intensity (cmp. yellow diamond overly weak mixing; the grey half-circle denotes a CLaMS-2D standard mixing parameter set). Analysis of the evolution of chemical species in the vortex shows that the larger O_3 loss in high-resolution studies is caused by less chlorine deactivation. The main deactivation mechanism under cold-vortex conditions (cmp. Figure 1) with severe denitrification is the reaction of ClO_x with NO_x, partly from outside the vortex: stronger mixing imports NO_x and HNO_3 into the vortex and ameliorates spring ozone loss.

Maps of chlorine nitrate and ozone

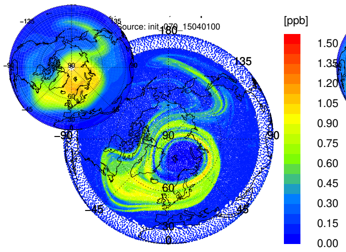

Figure 4. *$ClONO_2$ at the 475 K level on 1 April. The larger picture shows CLaMS results; for comparison, E39C simulated $ClONO_2$ is shown in the inset.*

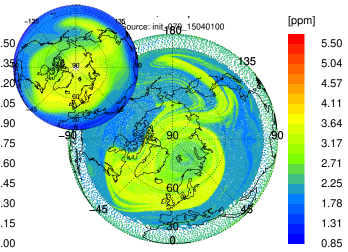

Figure 5. *Same as in Figure 4, but for CLaMS and E39C ozone*

CLaMS-2D simulated CH_4 on the 475 K isentrope agrees well with E39C tracer fields (not shown), enabling us to use 2D studies for comparative chemistry or mixing sensitivity experiments.

Ozone depletion and loss export to midlatitudes

Ozone loss in a 475 K E39C isentropic layer, derived from an O_3-CH_4 correlation is only 710 ppb. Compared to CLaMS simulations, ozone depletion is underestimated by 350 ppb. While half of this deviation can be explained by missing bromine chemistry, low resolution and numerical diffusion might be responsible for another 20% ozone loss underestimation.

	Acc ΔO_3	Corr ΔO_3	Deviation
C-2D, 50 km	1.07	1.15	—
C-2D,	0.98	1.07	7%
C-2D, 200 km	0.92	1.04	10%
C-2D, no Br_y	0.83		150 ppb
C-2D, no sedi	0.80	0.83	180 ppb
E39C, <400 km	—	0.71	?

Table 1. *Ozone loss determined from inert O_3 tracer (Acc ΔO_3, in ppmv) and determined from O_3-CH_4 correlation (Corr ΔO_3). The last column denotes the effect of a parameter change in CLaMS (C-2D, 100 km if not shown otherwise) simulations. Since mixing is sensitive to meridional gradients, the resolution for E39C is assumed to be better than their meridional grid (3.75°).*

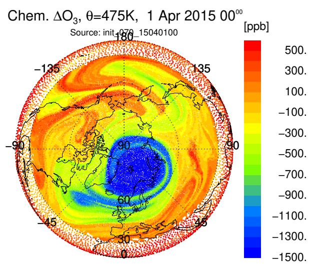

Figure 6. *90-day accumulated chemical ozone depletion, shown for 1 April on the 475 K isosurface.*

Vortex-processed air is exported into midlatitude regions: For a first 3D study, 50% of midlatitude air (outside vortex and between 30° and 60° N was influenced by polar processes. Though ozone loss amounts to only 4% on average, vortex extruded filaments are depleted by up to 25% (mean 10% or 390 ppb).

➪ Challenge: Derivation of CTM-derived offline correction terms to existing GCM predictions for ozone loss.