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Lagrangian Modelling of Vertical Transport and Chemical Ozone Destruction

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Studies on Vortex Dynamics for the Winter 2002/03: Transport and Mixing

The polar vortex of the winter 2002/03 was heavily disturbed by planetary waves. After having been split into two lobes during mid January 2002, a re-merge of the vortex was observed a few days later. Besides causing vigorous mixing in the vicinity of the vortex edge the repeatedly splitting, folding and re-merging lead to strong filamentation of the interior of the lower stratospheric vortex with mid latitudinal air masses being folded into the vortex.

Figure 1 (left column) shows the situation of the polar vortex on January 19, 2003. The distribution of the inert tracer P4 on the 450 K isentropic level shows air masses originating in the vortex core. Tracer values different from 1 and 0 show the effects of mixing. The vortex is strongly elongated, almost splitting into two secondary vortices. Distinct filaments of vortex air are wrapping around anticyclones which are created due to PV conservation.

On January 23 the two vortices are about to re-merge, a thin filament of mid latitudinal air being trapped between them (see Fig. 1, right column). The tongue of vortex air moved to the mid latitudes observed on January 19 has been mixed into its environment to a large degree.

The dynamics of the polar arctic stratosphere leads to enhanced transport in and out of the polar vortex (see Fig. 2). The total effect on the lowest part of the vortex is about 25%, but only 2% when the whole simulated vortex between 325 K and 600 K is considered. About 10% of the vortex mass is exchanged by horizontal transport and mixing, being substituted by vertical transport from the middle and upper stratosphere.

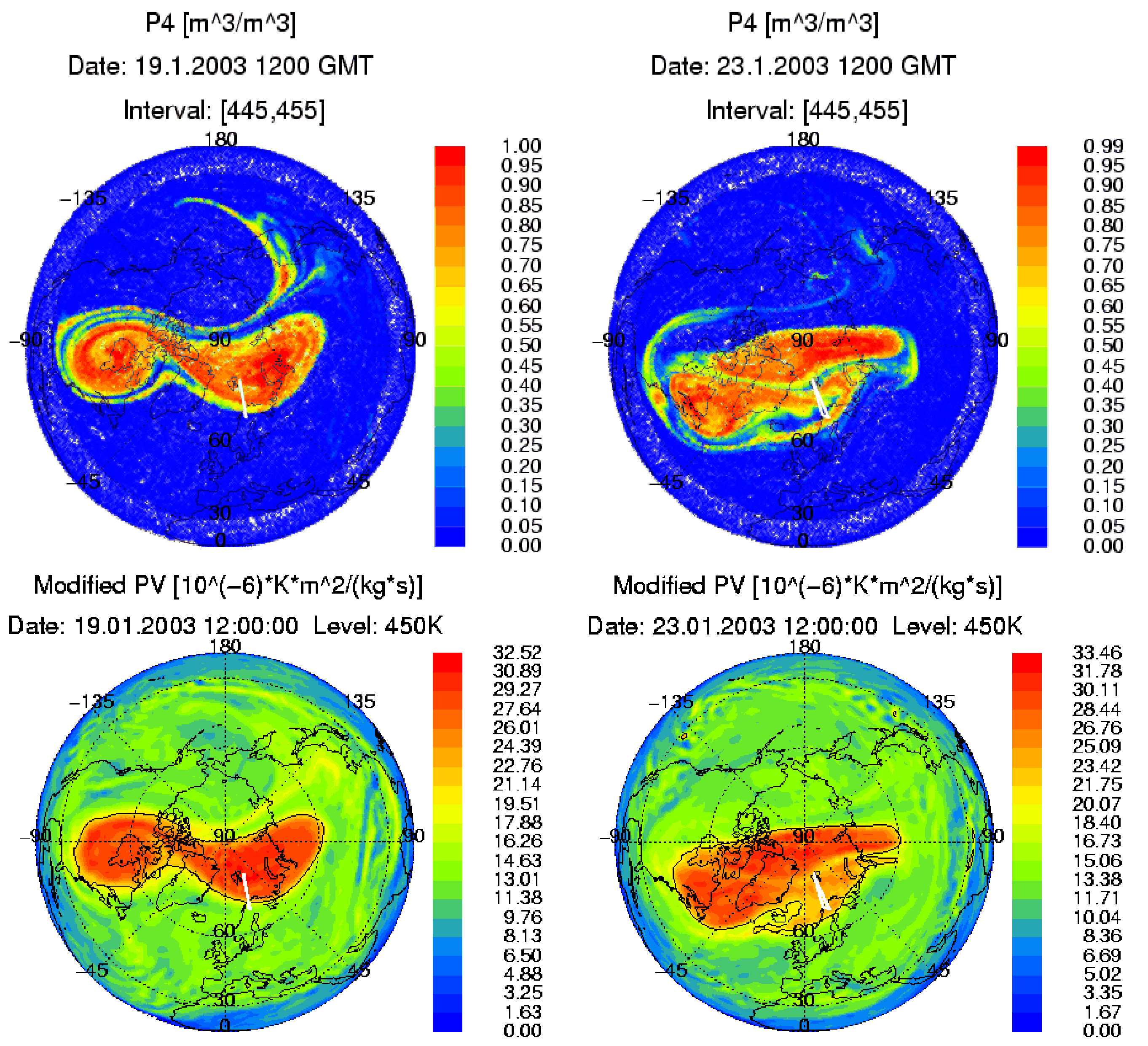


Figure 1: Horizontal distribution of the tracer P4, marking the interior of the vortex core, on the 450 K level for January 19, 2003 (upper left) and January 23, 2003 (upper right). The corresponding mPV distribution is shown in the lower row.

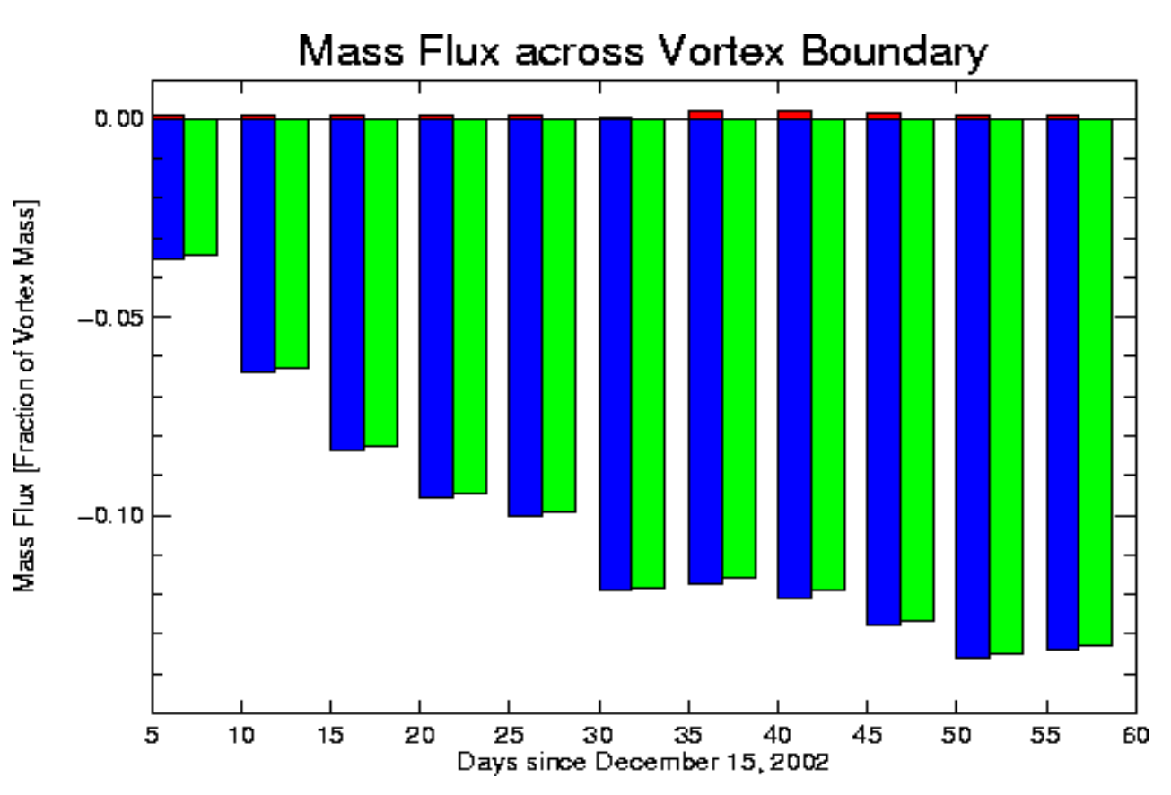
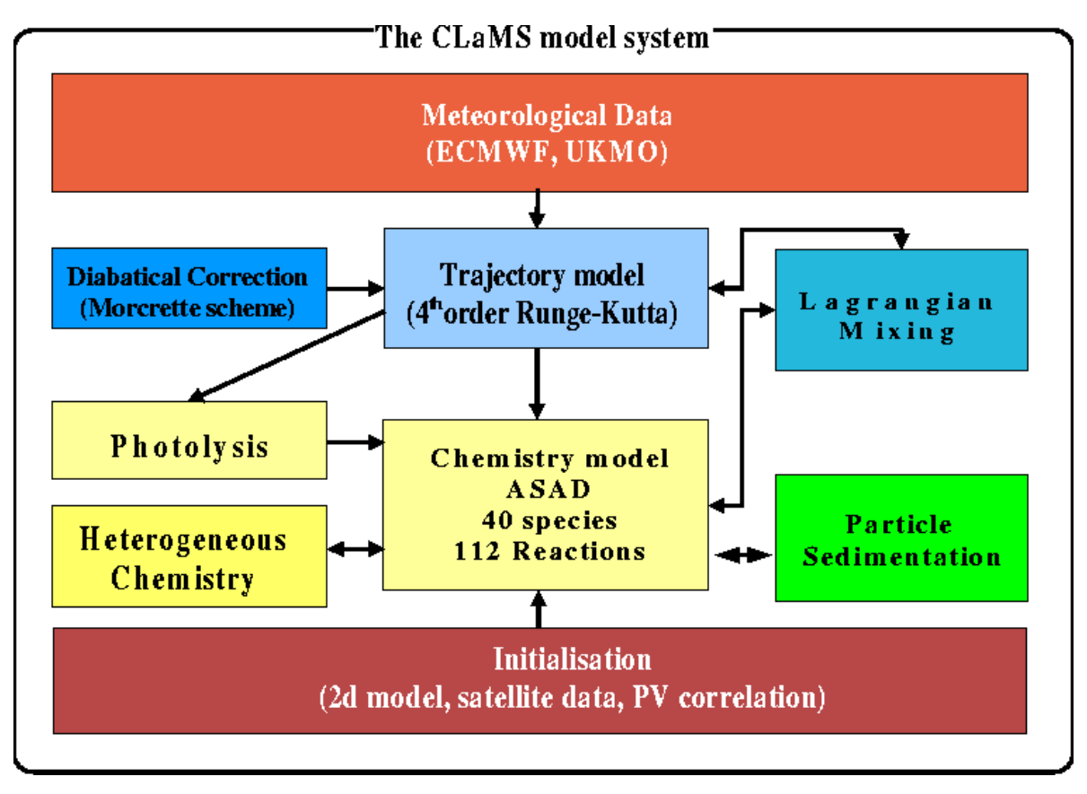


Figure 2: Accumulated cross-boundary flux in the region between 325 and 600 K displayed as fraction of vortex mass. The in, out and net fluxes are shown in red, blue and green, respectively. The vortex edge was computed from ECMWF data using a value of 21 mPVU.


The CLaMS model system

Meteorological Data (ECMWF, UKMO)

Diabatical Correction (Morcrette scheme)

Trajectory model (4^{th} order Runge-Kutta)

Lagrangian Mixing

Photolysis

Chemistry model ASAD 40 species 112 Reactions

Heterogeneous Chemistry

Particle Sedimentation

Initialisation (2d model, satellite data, PV correlation)

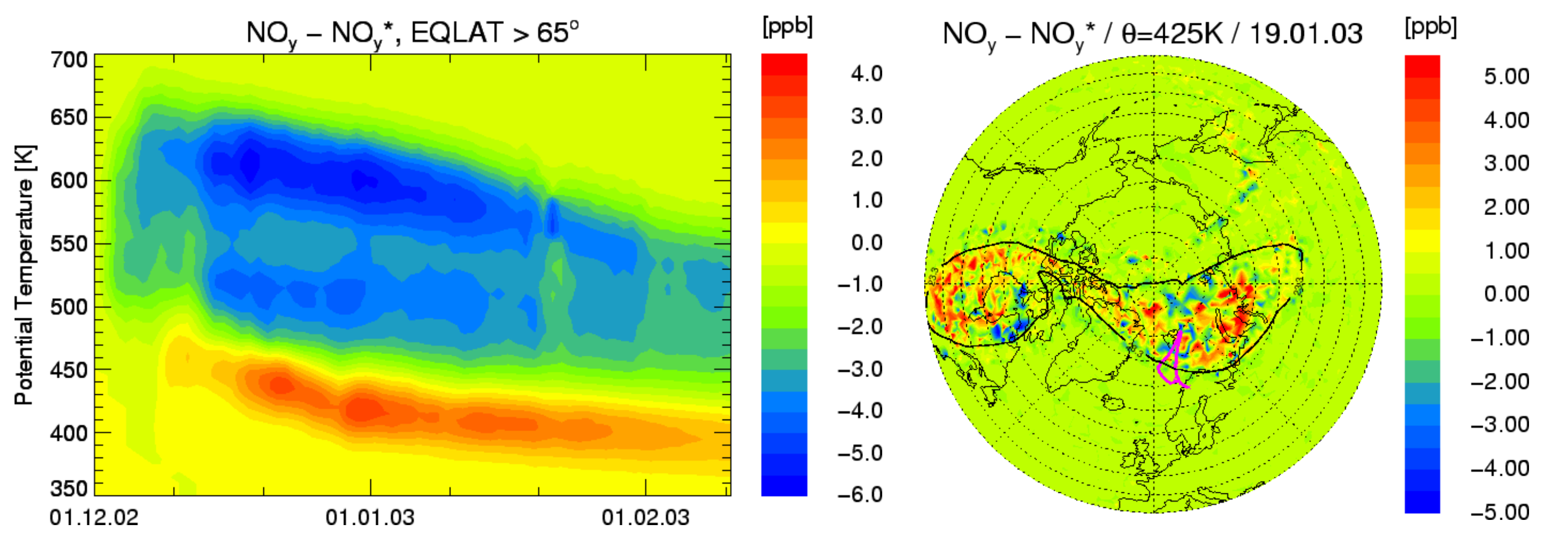


Figure 3: Deviation of NO_y from NO_y^* as temporal evolution poleward of 65 degrees equivalent latitude (left) and on the 425 K level on January 19, 2003 (right).

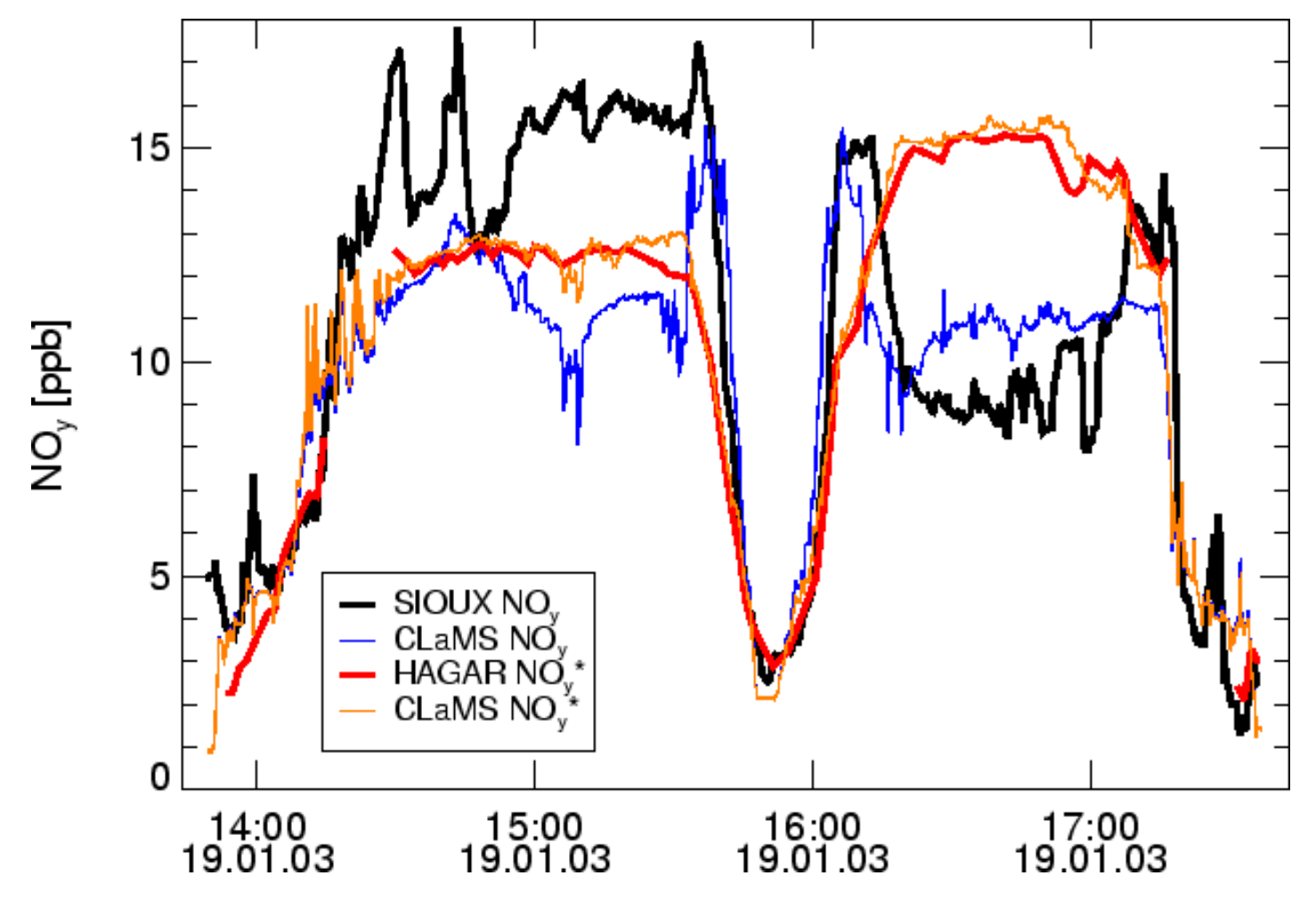


Figure 4: Measurement of NO_y (in black) obtained on the Geophysica flight on January 19 , 2003, and derived NO_y^* (red), together with CLaMS results (blue and orange, respectively) interpolated onto the flight path corresponding to the pink line in Figure 3 (right).

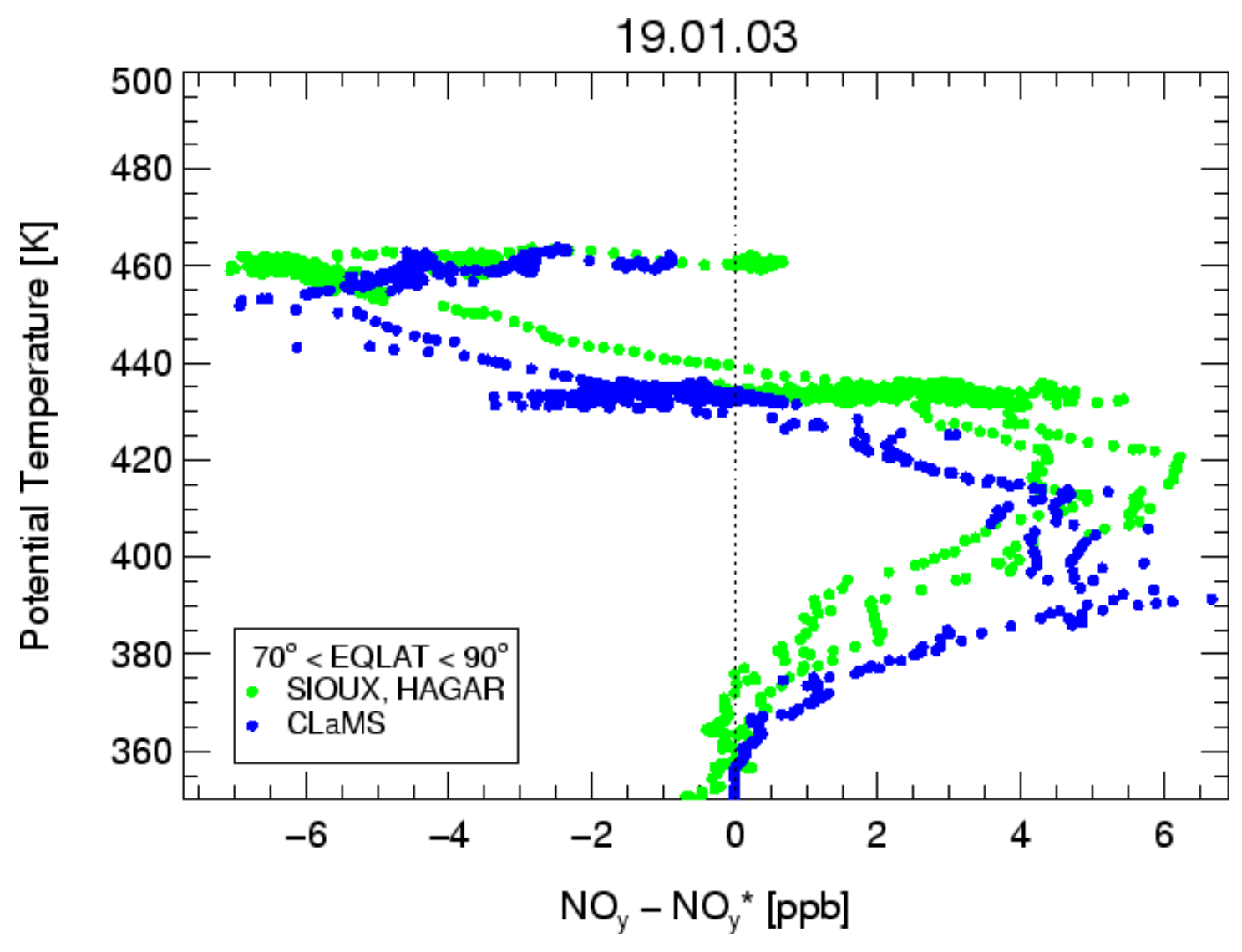


Figure 5: Deviation of NO_y from NO_y^* along the flight path of the Geophysica as function of Potential Temperature. SIOUX and HAGAR measurements are shown in green, CLaMS results in blue. The vertical shift between measurements and the results of the simulation may be due to the vertical resolution of CLaMS.

Studies on Chemistry for the Winter 2002/03: Re- and Denitrification and Ozone Loss

The measurements obtained during the european field campaign EUPLEX gave strong evidence of re- and denitrification processes inside the polar vortex. Utilizing the CLaMS model these processes were simulated allowing for interpretation beyond the observations. The newest developments of the CLaMS model include an enhanced parameterization for the growth, transport and sedimentation of large NAT particles, so-called 'NAT-Rocks', which may be responsible for the strong de- and renitrification processes. Figure 3 (left) shows the temporal evolution of the deviation of the models NOy from NOy* poleward of 65 degrees equivalent latitude, usually being a good indicator for re- and denitrification.

In the mid of December 2002 the vortex interior is characterized by very low temperatures, allowing for the nucleation and growth of large NAT particles. The horizontal distribution of the above mentioned quantity on the 425 K isentropic surface (see Figure 3, right) shows a strong inhomogeneity of de- and renitrification areas. Measurements obtained during a flight on January 19, 2003, (flight path corresponds to the pink line in Fig. 3) are shown together with CLaMS results in Figure 4 and 5. They are in general in good agreement with the observations, although CLaMS shows stronger denitrificaton on the higher flight level. This is possibly due to the patchy structure mentioned above and the comparatively coarse CLaMS resolution.

The ozone destruction derived from this simulation for the 500 K isentropic level is shown in Figure 6 (left). Another simulation has been carried out to investigate the total amount of ozone destruction as compared to observations. Figure 6 (right) shows the difference between ozone transported as an inert tracer by CLaMS and ozone derived from ENVISAT observations inside the vortex. The vortex is considered as all air masses with at least 80 % vortex air with respect to the beginning of the simulation, indicated by the purple line. The lower panel of Figure 6 (right) shows the total ozone loss distinguishing between pure vortex air masses and air masses with mixed in mid latitude air.

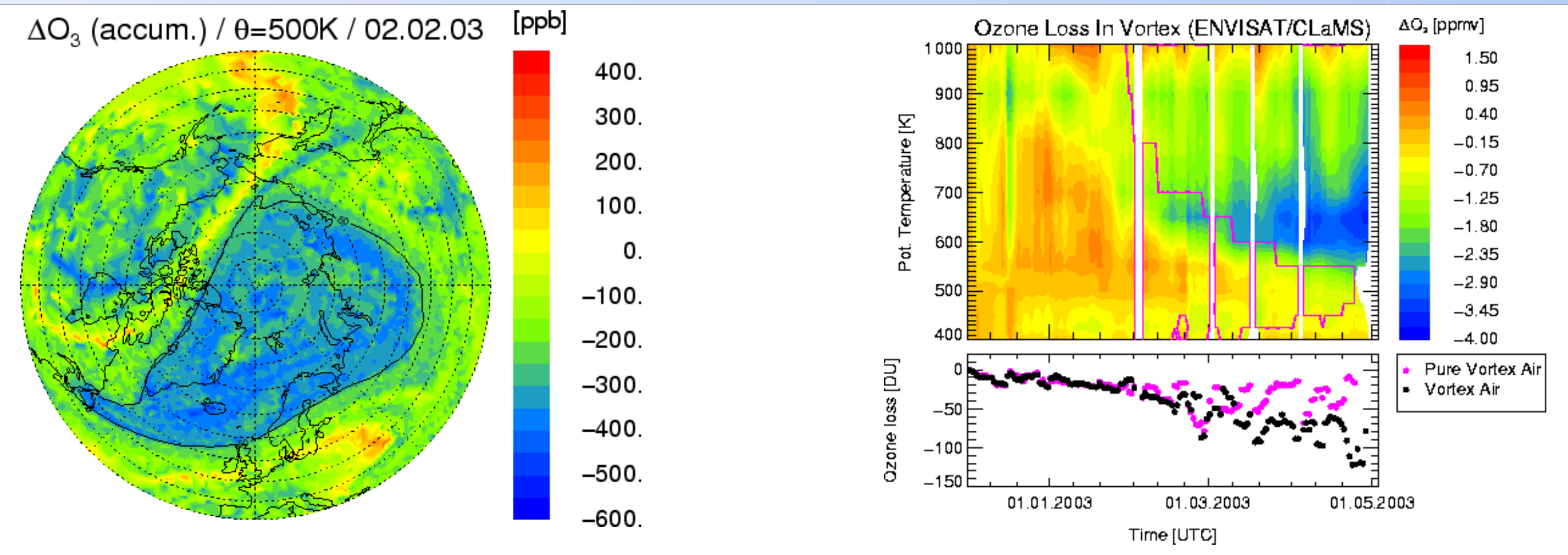


Figure 6: Simulated ozone loss on the 500 K level (left) and temporal evolutionof the difference between an inert tracer and ENVISAT observations (right).

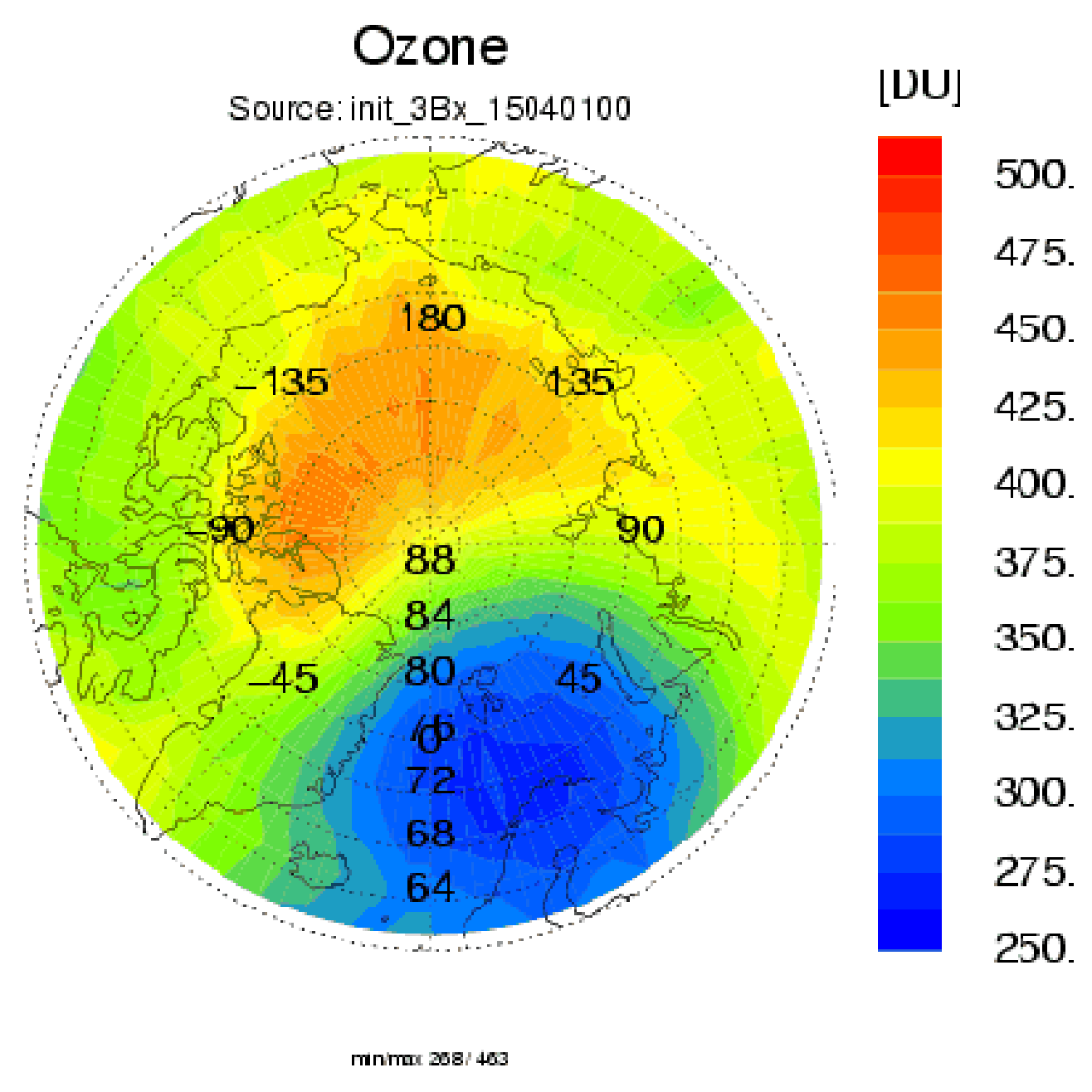


Figure 7: Total ozone in DU for a CLaMS full chemistry run initialized and driven by the dynamics of E39/C.

Climate-Chemistry Interaction

One of the main objectives of the project is the investigation of the sensitivity of stratospheric chemistry to climate signals. For this purpose CLaMS was driven with the dynamics of certain winter episodes carried out with the E39/C. GCM-simulated ozone loss for the time slice experiments '1990' and '2015' was determined with a methane-ozone correlation obtained on the 1st of January. For the winter with the largest ozone loss on the 475 K isentropic level (simulated winter 2015/58), multi-level and sensitivity studies were performed. Figure 7 shows the ozone column simulated by CLaMS based on the GCM initialization for the '2015' time slice experiment. The values (~268 DU) are significantly lower than minimal ozone values simulated by E39/C There, the minimal arctic column ozone value is reported around 290 DU. To identify the underlying reasons for the discrepancy in simulated ozone loss, sensitivity studies for different mixing parameters, model resolutions and chemical setup were performed. Figure 8 shows the accumulated ozone loss for a number of simulations carried out with ClaMS. Neglection of bromine chemistry leads to an underestimation of ozone loss of 17% (compare #9, 1080 ppbv) Reduced ozone loss in the sensitivity studies were attributed to increased deactiviation of active chlorine species to the reservoir species chlorine nitrate. This sensitivity and the underestimation of ozone loss (total column and volume mixing ratio) in previous GCM studies point to overestimated numerical diffusion in E39/C, which would import nitrous oxides from mid latitudes into the polar vortex, thus leading to early deactivation.

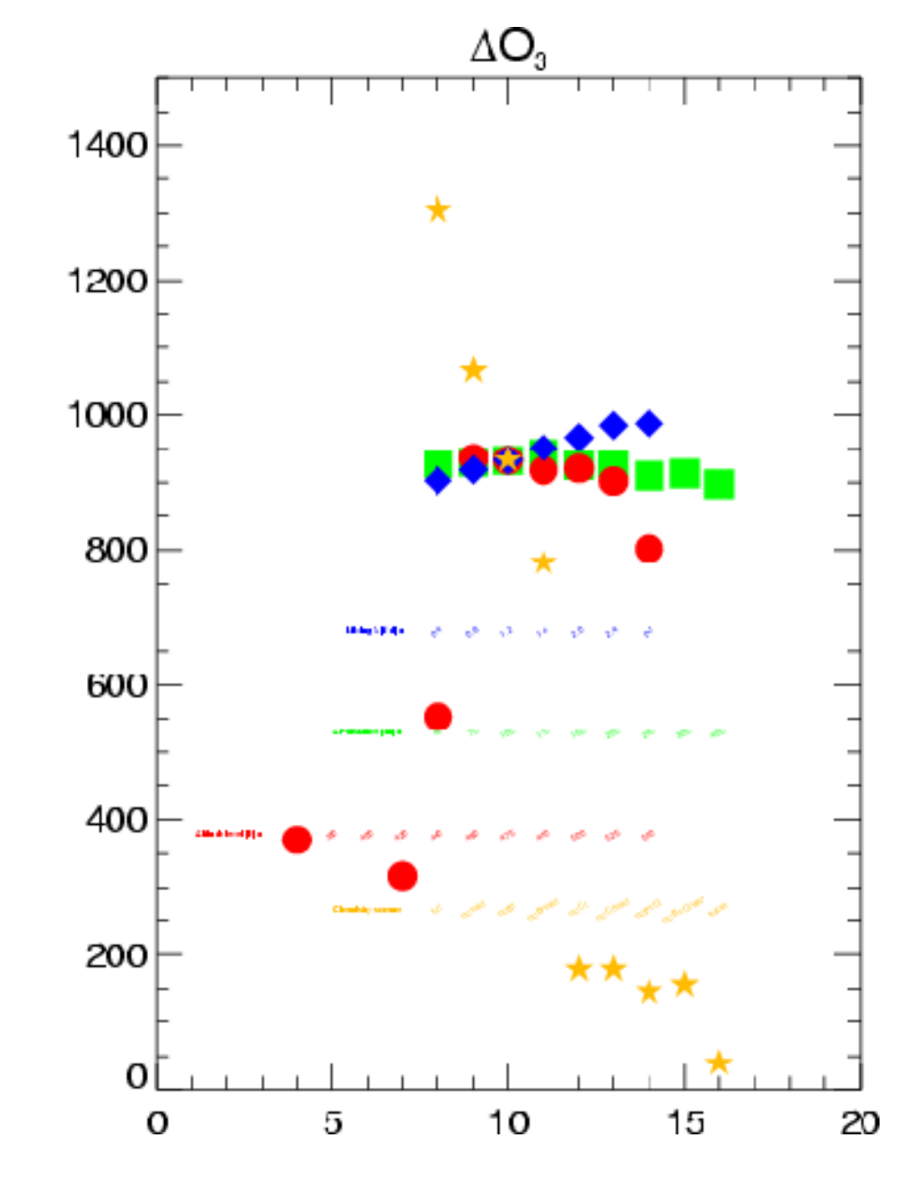


Figure 8: Accumulated ozone loss on 475 K for different simulation setups: Reduced mixing (blue diamonds), coarser resolution (green squares).

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