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Atmospheric Chemistry and Physics Discussions

Interactive comment on "A model study of the January 2006 low total ozone episode over Western Europe and comparison with ozone sonde data" *by* A. Mangold et al.

A. Mangold et al.

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First of all, we would like to thank very much the referee for the very constructive and helpful comments, which helped to improve the manuscript.

Specific comments:

Referee:

I would also encourage the authors to shorten the manuscript, as some sections (e.g Discussion section 7, or model modules on page 8) are quite lengthy.

Answer:

We knew about the length of the manuscript, however, found it difficult to submit a shorter one, given the fact that we used three models, data of six sounding stations, and investigated both dynamic and chemical contributions to the event. This implies a lot of necessary sections and descriptions. However, we shortened some sections as follows:

Section 2.3 Description of models

P6010, line 19 to p6011, line 10, CLaMS module, rewritten as follows:

For this study the three-dimensional CTM CLaMS (Chemical Lagrangian Model of the Stratosphere), which simulates the dynamics and chemistry of the atmosphere along trajectories of multiple air parcels (McKenna et al., 2002a,b), was run for whole January 2006. The vertical coordinate is potential temperature with 32 levels between Theta =350 and 700 K, corresponding to an average vertical resolution of Theta =11 K (or about 500 m). Mixing is simulated at those locations where strong wind shear occurs using a Lagrangian mixing algorithm (Konopka et al., 2004, 2005). Meteorological fields were taken from 6-hourly operational ECMWF analyses. Ozone was treated as passive tracer and was initialised with version 1.5 data measured by the Microwave Limb Sounder on the EOS-AURA satellite. Similar to the method described in Grooß and Müller (2007), MLS ozone data between 1 and 4 January 2006 were mapped to the synoptic time 1 January 2006, 12:00 UT, onto a regular 2degree latitude x 6degree longitude grid using the CLaMS trajectory module.

P6011, line 11 to p6012, line 4, KASIMA module, rewritten as follows:

The three-dimensional CTM KASIMA (KArlsruhe SImulation model of the Middle Atmosphere) is a global circulation model including stratospheric chemistry for the simulation of the behaviour of physical and chemical processes in the middle atmosphere (Reddmann et al., 2001; Ruhnke et al., 1999). Data from of a multi-year run (1972-2006) were used in this study. The vertical coordinate is pressure. Pressure altitude is calculated as z = -H ln(p/p0) where H=7 km is a constant atmospheric scale height, p is the pressure, and p0=1013.25 hPa is a constant reference pressure. The vertical res-

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olution is 0.75 km between 7 and 22km, with an exponential increase above. For the meteorology module of KASIMA, the nudged model version has been used (Kouker et al., 1999). In this version, the model is nudged towards the operational ECMWF analyses of temperature, vorticity and divergence. The model run was initialized for 1 April 1972, with adjusted 2-D-model data of the Max Planck Institute (MPI) for Chemistry in Mainz (Gidel et al., 1983; Grooß, 1996). Tropospheric trends of source gases as N2O, CH4, and CFCs have been prescribed during the model run according the IPCC/WMO baseline scenario Ab (WMO, 2003). The photoloysis rates were calculated online in KASIMA by using the Fast-J2 model of Bian and Prather (2002).

P6012, line 5-25, E5/M1 module, rewritten as follows:

The ECHAM/MESSy (E5/M1) atmospheric chemistry model is a numerical chemistry and climate simulation system that includes sub-models describing troposphere and middle atmosphere processes and their interaction with oceans, land and human influences (see Jöckel et al., 2006, and references therein). It uses the first version of the Modular Earth Submodel System (MESSy1; Jöckel et al., 2005) to link multi-institutional computer codes. The core atmospheric model is the fifth generation European Centre Hamburg general circulation model (ECHAM5; Röckner et al., 2006). E5/M1 was used to perform a six-year simulation (2000–2006). Temperature, vorticity, divergence and ground pressure were nudged towards ECMWF operational analysis data up to 10 hPa. The chemical initialisation was done with data of the S1-simulation of the MPI for Chemistry in Mainz, Germany (T42L90, 1 January 1998–31 December 2005; Jöckel et al., 2006). The most important submodels used in this simulation are: OFFLEM, ONLEM, and TNUDGE (prescribed, calculated, pseudo-emissions, respectively, of chemical species, Kerkweg et al., 2006), MECCA (gas-phase chemistry, Sander et al., 2005), CLOUD (cloud cover and microphysics, Tost et al., 2007a), LNOX (lightning NOx, Tost et al., 2007b), and PSC (processes related to PSCs, Buchholz, 2005).

Section 3 Observation of the low ozone event

P6015, lines 6-14 suppressed (between When comparing the total ozone … and … will be given in Sect. 6). We think this part can be suppressed because of (i) the detailed quantification of the ozone column decrease is given later, and (ii) that quick estimate of the ozone decrease is based on assumptions about the upper-stratospheric ozone concentration.

Section 7 Discussion, P6026, line 22 to p6027, line10 – paragraph suppressed.

We think that the suppression can be justified because of (i) the total ozone column of the soundings is, as stated, based on assumptions, and (ii) the height boundaries of Theta = 300 K and 700 K are already well reasoned in the manuscript.

Referee - Technical corrections:

Referee:

1) A few column ozone maps derived from satellite observations would be useful in describing the events.

Answer:

In a previous to the submitted version of the article we had maps of the daily averages of the total ozone distribution for the time period of the event, derived from the WOUDC (World Ozone and Ultraviolet radiation Data Centre; www.woudc.org) network of the WMO. However, we omitted the maps because of (i) such maps are easily accessible on the WOUDC-website, (ii) Keil et al. (2007) showed already similar maps, and (iii) not to lengthen the respective section. We also thought about including ozone maps derived from satellite observations, but omitted this idea. We considered the Brewer, Dobson and sounding observations as sufficient, being reference observations for the WOUDC. In addition, with respect to the analysis of the ozone reduction at the six sounding stations, high vertical resolution observations are preferable. Furthermore, showing additional satellite-ozone maps would have meant to compare, at least briefly, satellite and ground-based observations and to describe (albeit briefly) the satellite

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data characteristics. This would have unproportionally lengthened the respective sections (colliding also with the referee comment to shorten the article).

Referee:

2) p6, line 156. It is unclear whether the ECMWF analyses had a spatial resolution of 1 degree, or of 0.5 degree as suggested on line 159.

Answer:

The original ECMWF analyses had a spatial resolution of 0.5 degree (T511), but our retrieval from the ECMWF archive requested the fields interpolated on a 1 degree grid, corresponding to the CLaMS resolution. In order to avoid possible misunderstandings, we rewrote section 2.2 Meteorological data:

Meteorological fields of the horizontal and vertical winds, temperature, specific humidity, and pressure were retrieved from analyses belonging to the operational ECMWF IFS model in January 2006 (T511L60, i.e. 60 height levels from surface pressure to 0.1 hPa, spatial resolution corresponding to a 0.5 degree x 0.5 degree grid). Our retrieval for the CLaMS model requested the meteorological fields interpolated on a 1 degree x 1 degree grid (i.e. linear interpolation after spectral truncation), for the 60 height levels at 00:00, 06:00, 12:00, 18:00 UT, and for whole January 2006.

Referee:

3) p8, line 218. It is unclear what the two standard deviations are. One measure the inter-annual variability, but what is the overall variability ?

Answer:

The overall variability gives the 95%-percentile bound for an individual daily value. For this end, all values of all years (1971-2006) of the populations to calculate a running mean of day X +/- 15 days are taken and the respective 2sigma standard deviation is calculated. In the case of the inter-annual variability, only the running means of day X

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+/- 15 days of each year are taken. Then the 2sigma standard deviation is calculated from the population of the yearly running means. In other words, the first standard deviation is a measure of the variation of the total ozone column from day to day. The inter-annual variability on the other hand is a measure of the variation of the total ozone column on a longer perspective.

The respective paragraph (p6013, line4ff) of the article has been rewritten:

The long-time mean (since 1971) of the Dobson measurements and the respective overall and interannual variability are given and the daily total ozone column averages of 2006 measured by Brewer No. 16 are superimposed. The overall variability considers all values of all years of the populations to calculate a running mean of day X +/- 15 days, whereas for the interannual variability only the running means of day X +/- 15 days of each year are considered. Thus, the record low of 200 DU on 19 January 2006 was distinctly outside the 95%-percentile-bounds of both the day to day variability and the variation of the total ozone column on a longer perspective. It corresponded to 130 DU less than the long-time mean for 19 January.

Also the caption of Figure 1 has slightly been adapted (… (see also text) … included):

Total ozone column measured at Uccle, the black line is the mean of all Dobson measurements since 1971, the light and dark grey-shaded area represent the 95%-percentile-bound (or 2sigma error) of the overall and the interannual Dobson time-series variability, respectively (see also text). The daily averages of 2006 measured by Brewer No. 16 are given in red.

Referee:

4) p9, line 264. The authors do not mention PSCs observations from satellite. Are there some ENVISAT observations that could be of interest for confirming the occurrences of PSC in these regions.

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Answer:

Yes, there are. Observations of the SCIAMACHY instrument on ENVISAT reveal clear signs for an increased occurrence of PSCs over Western and Middle Europe between 17 and 20 January 2006 (http://www.iup.uni-bremen.de/˜sciaproc/PSC/PSC_2006_S00.html). For a reference of these observations see von Savigny et al. (2005). In a previous to the submitted version we mentioned these observations, however, we preferred to mention observations published in a journal (Keckhut et al., 2007). As the SCIAMACHY PSC maps are easily accessible on the respective website, we will not include them in the revised version of the article.

Referee:

5) p10, line 285. As the PV=2 contour delineates stratospheric air masses, it would be very useful to have it outlined in Figure 5.

Answer:

The PV=2 contour has been marked with a thicker black line now and there is a respective remark in the figure caption.

Referee:

6) p13, line 388. It is unclear why the active chlorine is shown only for KASIMA, but not for E5/M1. It would have been interesting to see the difference in chlorine activation in both models, rather than showing the chlorine reservoirs for one of the model.

Answer:

In Figure 13, graphs showing ClOx values from E5/M1 have been included. With respect to the differences in chlorine activation in the two models, we refer to our respective answer to Referee #1, as Referee #1 commented also on that issue. The caption of Figure 13 is adapted accordingly:

Active chlorine (ClOx,, top row), chlorine nitrate (ClONO2, middle row) and hydrochloric

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acid (HCl, bottom row) as simulated by E5/M1 for 17 to 20 January 2006, 12 UT, for Theta = 500 K; the six sounding stations are marked by stars (different colours for better visibility).

Referee:

7) p17, line 525. This whole paragraph is very unclear. The authors mention “Change” but it is unclear what “Change” means. Change with respect to what ? This paragraph would gain to be rewritten.

Answer:

We assume that the Referee refers to the cumulated chemical ozone change as it is modelled by KASIMA. We recall (as stated on p6019, line 22ff) that this term comprises the ozone variation due to chemistry (also non-halogen reactions are taken into account) over the last 24 hours at each model grid point. Changes induced by transport are neglected. We rewrote the paragraph in question (p6025, lines 7-21):

Comparing the values between 0.7 and 1.5 DU for the ozone variation due to chemistry with the overall ozone column decrease described above (between 74 and 108 DU), it becomes obvious that ozone chemistry contributed a traceable but very marginal part. Depending on station and on observation or model simulation as basis for the overall ozone column decrease, the fraction of the ozone variation due to chemistry varied between 1 and 3%. The overall average was 2%. To estimate the error, one has to consider the uncertainties of the sonde measurements (between 5 and 17%, depending on altitude), of the models ozone mixing ratios, temperature and pressure profiles, and of the ozone variation due to chemistry as simulated by KASIMA. The final error for the cumulated chemical ozone depletion may thus be estimated to be around 50%. The absolute amount in DU of instantaneous, in-situ chemical ozone depletion was thus within the overall error of calculating the total ozone column (see Sect. 2).

The sentence p6025, lines 9-11 was moved to the end of the former paragraph (p6025,

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line 6) and slightly changed:

Over 80% of it took place above Theta = 450 K, and around two thirds in the layer between Theta = 450 and 550 K.

Accordingly, the sentence on p6033, lines 20-22, was adapted:

At all stations, the cumulated chemical ozone change occurred mainly in the mid-stratosphere, with over 80% above Theta = 450 K, and around two thirds in the layer between Theta = 450 and 550 K.

Referee:

8) That the model reproduces well the formation and evolution of the event may be an overstatement. In Figure 11, the vertical ozone profiles from the models, except for CLAMS, do seem very different from the observations. Isn’t it more fair to say that the models reproduce analogous events but exactly not collocated in time and space with the soundings?

Answer:

As all models reproduce in general the formation and evolution of the event, we still think that it is, from a qualitative point of view, justified to say that the models reproduce well the episode. With respect to the quantitative comparison, the picture is different, indeed. But this is already stated several times in the article, e.g., p6019, lines 7-12. However, we went through the respective sections to adapt the quality statements where appropriate.

P6004, line 15: well deleted

P6017, line25: KASIMA also reproduced very well: very deleted.

P6018, lines 4-7 changed to:

The CCM E5/M1 mainly overestimated the total ozone column during the episode and

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the core of the low total ozone episode on 17 and 18 January was located too far to the west. However, E5/M1 captured some features, e.g., at Prague on 16 January, at Uccle on 18 January, and at Lerwick on 21 January.

P6022, lines 19-21: sentence changed to:

KASIMA captured well the qualitative distribution, but not the absolute ozone change values, especially above Theta = 500 K (e.g., at Lerwick, De Bilt and Uccle).

P6033, lines 6-7 qualitative added:

all three models reproduced well the qualitative evolution and formation of the event.

P6033, line 10:

and captured well ozone peaks: well deleted.

The Referees latter comment is addressed in the discussion section:

P6028, line 26, sentence added:

This might explain why the models, and especially KASIMA and E5/M1, reproduce qualitatively the low total ozone episode, but have difficulties to model it quantitatively, and to exactly locate it in time and space.

References:

Keckhut, P. et al., Observations of Polar Stratospheric Clouds down to the Mediterranean coast, Atmos. Chem. Phys., 7, 5275-5281, 2007. Keil, M. et al., The January 2006 low ozone event over the UK, Atmos. Chem. Phys., 7, 961-972, 2007. von Savigny, C. et al., Detection and mapping of polar stratospheric clouds using limb scattering observations, Atmos. Chem. Phys., 5, 3071-3079, 2005.

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