

Interactive comment on “Evaluation of CLaMS, KASIMA and ECHAM5/MESSy1 simulations in the lower stratosphere using observations of Odin/SMR and ILAS/ILAS-II” by F. Khosrawi et al.

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We thank reviewer 1 for the constructive, helpful criticism. We followed the suggestions of reviewer 1 and revised the manuscript. However, we feel that the major part of the criticism by reviewer 1 arises due to the fact that reviewer 1 is not separating tracer-tracer correlations in the classical sense as described e.g. by Proffitt et al. (1993), Müller et al. (1996) and Tilmes et al. (2004) from the O₃-N₂O diagnostic introduced by Proffitt et al. (2003) and extended by Khosrawi et al. (2004, 2006, 2008). This distinction is important because the tracer-tracer correlation in the classical sense are designed in a way to eliminate diabatic descent from the analysis which (among other things) requires the correlations to remain compact. For the method put forward by Proffitt et al. (2003) and applied in our analyses, in contrast, diabatic descent

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is important (as the analyses is done by binning the data by potential temperature) whereas compactness of the correlations is much less relevant. We have improved the manuscript to make this distinction clearer. A detailed response to the comments of reviewer 1 follows below.

General comments

It is indeed a challenge to untangle the effects of chemistry and dynamics on the tracer-tracer correlation shape. As a way to avoid the difficulties which arise due to the application of tracer-tracer correlations in the classical sense, Proffitt et al. (2003) suggested a somewhat different way to use tracer-tracer correlations which help to separate O_3 variability due to latitudinal transport from photochemical changes. In their study, Proffitt et al. (2003) seasonally averaged lower stratospheric distributions of ozone and nitrous oxide which were binned by potential temperature or altitude. Here, we use monthly averages instead of seasonal averages which is possible due to the high spatial and temporal resolution of the satellite data sets. This is already discussed on P1986 L7-12, but we included the following sentence in the introduction to make this more clear: *In this method, tracer-tracer correlations are used in a somewhat different way as in the classical sense which helps to separate O_3 variability due to latitudinal transport from photochemical changes. Thereby, monthly averages of the O_3/N_2O correlation binned by potential temperature are derived.*

Specific comments:

(1) P1978 L22: We agree that the tracer-tracer distributions in the way that they are used here are influenced by both diabatic descent and chemistry. However, it is not correct that the statement in the abstract is based on the assumption that at 500 ± 25 K the correlation is influenced by chemistry only. At $500\pm$ K we considered both descent and chemistry. Descent is seen in the curve at 500 ± 25 K by an extension of the curve to N_2O mixing ratios $\ll 50$ ppbv and chemistry by the slope change and low ozone mixing ratios. Further, this statement relates to N_2O mixing ratios greater

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than 200 ppbv and thus relates to air masses of tropical character and not to air masses of polar character which are a subject of ozone chemistry and dynamics. These differences are caused by differences of air masses that are influenced by tropical air. However, we realise that we did not properly explain how we differentiate between diabatic descent and chemistry at 500 ± 25 K. Thus, we included the following sentence in section 4: *At and below 500 ± 25 K the curves are influenced by a combination of diabatic descent and polar winter ozone loss and descent is in these curves visible as an extension of the curves to N_2O mixing ratios < 50 ppbv.* Further, in Khosrawi et al. (2008) it was discussed, that the separation can be most easily performed when the polar regions are considered. Therefore, we included also the following text at the end of the paragraph: *However, as it was discussed by Khosrawi et al. (2008) diabatic descent is in the monthly averages to a certain extent masked by tropical ozone production when the entire hemisphere is considered. Thus, the separation in photochemical and dynamical processes can be most easily performed when only the polar regions are considered.*

We are not comparing completely different years (the data used is described in the paper at P1989 L22). The KASIMA, ECHAM5/MESSy and Odin/SMR data are for the year 2003. Solely, the data of CLaMS which is for the winter 2002/2003 does not match exactly. The same applies for the ILAS/ILAS-II data (1996/1997) which is only used as a second satellite data set. As discussed in detail in our previous publications (Khosrawi et al., 2006, 2008) differences between the years are small in the monthly averages and easy to distinguish from model deficiencies. However, in order to not solely referring to our previous publications we included a figure in chapter 4 which shows Odin/SMR measurements for three years (2003–2005) to demonstrate how similar the monthly averages of N_2O and O_3 between different years are. The following text has additionally been included: *In Figure 2 monthly averages of N_2O and O_3 derived from Odin/SMR at 500 ± 25 K and 650 ± 25 K for the year 2003 are compared with the two following years (2004 and 2005). As can be seen from this figure, differences between monthly averaged N_2O and O_3 binned by potential temperature are low between different years and*

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easy to distinguish from model deficiencies.

(2) *P1979 L15-19 / P2000 L27-P2001 L1*: We do not agree with the statement made by reviewer 1 that Huck et al. (2007) find that “the method used by Tilmes et al. (2004) and Lemmen et al. (2006) to derive ozone loss based on tracer-tracer correlations is likely to lead to an overestimation of chemical ozone loss”. The aim of the paper by Huck et al. (2007) is to introduce a new definition of ozone mass deficit, rather than to assess the reliability of methods to deduce ozone loss. For example, throughout the paper the word “overestimation” is never used.

The issue that ozone loss estimates based on tracer-tracer correlations had been raised by Michelsen et al. (1998) and Plumb et al. (2000). Müller et al. (2005) have clarified that Michelsen et al. (1998) used a different early vortex reference relation than is commonly applied and that therefore, it is incorrect to interpret the finding of Michelsen et al. (1998) as ‘mixing could produce about half the changes in the O₃/N₂O relation’ as it was done by Plumb et al. (2000). The issue has moreover been discussed in several publications e.g., Tilmes et al. (2004), Lemmen et al. (2000), Müller et al. (2007), Müller and Tilmes (2008); none of these papers concluded that an overestimation of chemical ozone loss is likely. Furthermore, we cannot find any statement in the Huck et al. (2007) publication saying that the tracer-tracer correlation is leading to an overestimation of ozone loss. However, we agree that the study of Eyring et al. (2006 and not 2007, since the 2007 study focus on future ozone loss which cannot be compared with measurements) should be cited here as well.

(3) *P1988 L5-10 / P1979 L23 / P1991 L12-17*: Indeed, Hegglin and Shepherd (2007) find that the correlations from ACE-FTS are not compact in the upper stratosphere. However, as already stated above we are not using tracer-tracer correlations in the classical sense and thus the results of Hegglin and Shepherd (2007) cannot be applied directly to our method. Further, most importantly, in the present paper we only consider the lower stratosphere, so that this upper stratospheric issue is less relevant

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here. Furthermore, the issue with the compactness of the correlations in relation to our method is already discussed in Khosrawi et al. (2006). It is also important to note that Odin/SMR has a much better coverage than ACE-FTS, so that the “sampling issue” identified by Hegglin et al. (2007) is not a problem for Odin/SMR. We now discuss the results of Hegglin et al. (2007) in the paper (introduction). The text is as follows: *It is important to distinguish between the method of Proffitt et al. (2003) which is used in the present study and the ozone-tracer relations in the classical sense (e.g. Proffitt et al., 1993; Müller et al., 1996; Tilmes et al., 2004). O₃-tracer correlations in the classical sense are designed so that they eliminate diabatic descent from the analyses which (among other things) requires the correlations to remain compact. For the method put forward by Proffitt et al. (2003), in contrast, diabatic descent is important whereas compactness of the correlations is much less relevant. Hegglin and Shephere (2007) proposed a further technique for using O₃-N₂O correlations to evaluate model results, namely, deriving equal area two-dimensional Probability Density Functions (PDFs) of O₃-N₂O pairs. They applied this technique based on Atmospheric Chemistry Experiment (ACE-FTS) data to evaluate the aspects of transport and polar ozone loss in the Canadian Middle Atmosphere (CMAM) model. Conversely, they used CMAM to assess sampling artefacts of the ACE-FTS (solar occultation) measurements. Further, the following sentence has been included in the introduction: However, both in Khosrawi et al. (2008) and the present study we focus on the lower stratosphere. The applicability of the method for model evaluation in the upper stratosphere has so far not been tested but will be a matter of future research.*

Reference curves have been derived from measurements and applied for e.g. estimating ozone loss since decades. A linear reference relationship between O₃ and N₂O has been first determined by Proffitt et al. (1989) from NASA ER-2 data for the 1987 Antarctic winter. Thereafter, a variety of reference curves have been reported from aircraft (Richard et al., 2001), balloon (Müller et al., 2001, 2003) and satellite (Müller et al., 1996) and shuttle data (Michelsen et al., 1998). The reference curves are all based upon measurements and have proven to be consistent with one another

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when compared seasonally and spatially, and have a clear dependence on latitude (Michelsen et al., 1998). Reference curves have also been applied by Proffitt et al. (2003) for distinguishing between air of polar and air of tropical character. We improved the last paragraph in section 4 to make this more clear. This paragraph reads now: *Reference curves have been derived from measured correlations of N₂O and O₃ since decades (e.g. Proffitt et al., 1989; Müller et al., 1996; Michelsen et al., 1998; Müller et al., 2001). These reference curves were derived from measurements made on different measurement platforms (aircraft, balloon, satellite and space shuttle) and have proven to be consistent with one another when compared seasonally and spatially, and to have a clear dependence upon latitude (Michelsen et al., 1998). The reference curves for May midlatitudes (ATMOS Shuttle 1985), April high latitudes (ATMOS Shuttle 1993) and November tropics (ATMOS Shuttle 1994) are shown in Figure 1 (bottom:right). These reference curves can be used to identify air of tropical character and air of polar character (Proffitt et al., 2003). In general, the tropical air has higher N₂O mixing ratios than the reference curve for the midlatitudes and the tropics while the mid-latitude air is centered around the midlatitude reference curve and the high latitude air has N₂O mixing ratios that are lower than the high latitude and midlatitude reference curves (Proffitt et al., 2003). The reference curves shown in Figure 1 (bottom:right) were used by Khosrawi et al. (2008) to identify air of polar character and air of tropical character measured by Odin/SMR.*

(4) P1986 L20-25: We agree, that the two processes cannot be separated by moving up by 150 K in potential temperature. We believe that our paper does not make this statement. However, as stated in our response to specific comment (1) there is a misunderstanding here. We can separate both processes at 500±25 K and improved the text in the manuscript to make this more clear. As stated in our response to comment (1) the following text has been added: *At and below 500±25 K the curves are influenced by a combination of diabatic descent and polar winter ozone loss and descent is visible in these curves by an extension of the curves to N₂O mixing ratios < 50 ppbv.* It is also correct, that we do not expect ozone loss in the midlatitudes or the tropics. However, these slope change in other latitude region is caused by air of polar character which

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are prevailing in these latitude regions (as discussed in the paper and by Proffitt et al. 2003 air masses are not truly isolated from each other). We do not argue against the results from Hegglin and Shepherd (2007) regarding the impact of transport but we do not see how they are contradicting the “general characteristics of monthly averaged N_2O and O_3 curves” we are discussing here. Solely, in our discussion the impact of chemical ozone loss on the curves is added.

(5) *P1992 L22-24*: We do not agree with this comment. Clearly, the impact of mixing on a tracer-tracer correlation depends on the specific air masses that mix. For example strong mixing within an air mass characterised by a linear tracer-tracer relation does not change the relation at all.

(6) *P1993 L1-5*: We thoroughly looked at both model and satellite data and could not find any mistakes in either the model simulations or the satellite data. The Odin data have been thoroughly validated and showed a good agreement compared to several different data sets. The only possibility to find out if this differences are caused by uncertainties in the Odin/SMR data is to derive a 1-year data set from an other globally measuring satellite. Such a comparison is intended for future studies, however, beyond the scope of this study. Thus, for this paper we would prefer to keep the data points in the plots.

(7) *P1994 L19*: Here, we use the ILAS/ILAS-II 1-year data set derived by Khosrawi et al. (2006). Indeed, ILAS and ILAS-II measured during different years. However, in Khosrawi et al. (2006) it is shown that these two data sets can be combined. Note, that the O_3 - N_2O correlation as we use them here are less sensitive to seasonal variations in diabatic descent than, e.g., vertical tracer profiles. Both satellites measured during different periods of the year, however, there was an overlap of three months. The months taken here (Nov to Feb) are from ILAS and thus from the year 1996/1997. The differences seen in the figure are not caused by the fact that ILAS measured in a

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different year. The fact that differences are low between different years was already discussed in Khosrawi et al. (2004, 2006, 2008). However, in the revised version of the paper we included a figure comparing Odin/SMR monthly averages of nitrous oxide and ozone for three years showing that differences between different years are low and thus can be easily distinguished from model deficiencies (see response to specific comment (1)). To make it more clear that we use the combined data set of ILAS and ILAS-II we included in section 3.2 the following text: *To derive a one year data set for the northern and southern hemisphere high latitude region the measurements of ILAS and ILAS-II were combined (Khosrawi et al. 2006). Thus, the months from January to June and November and December are covered by ILAS and the months from July to October by ILAS-II. The comparison of ILAS with ILAS-II for the months where both instruments measured showed a good agreement between both data sets and demonstrated that differences between the different years considered are low in the monthly averages of N₂O and O₃.*

(8) P1995 L14: see our response to comment (2)

(9) Figures 8 and 9: Odin/SMR is taken as the reference data set for estimating the average differences. Thus, the differences in the O₃ mixing ratio between the models and ILAS/ILAS-II, respectively, from Odin/SMR are calculated. We improved the text in the figure caption to make this more clear. Indeed, ILAS and ILAS-II measured during different years. However, as stated in our response to comment (7) Khosrawi et al. (2006) showed that a combination of both data sets is possible though the measurements were performed during different years. As stated in the response to comment (7) we included a sentence in section 3.2 to make this more clear.

(10) Figures 2, 3 and 4: It is indeed true that there seems to be a problem in the tropics. However, we can exclude that there is something wrong with the binning in the tropics since the binning is done in the same way for all latitude regions. However, as described in the paper, an artificial extension of the curves to higher N₂O values can

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occur due to the fact that the statistical uncertainty of Odin/SMR is in the order of our chosen N_2O bins. The Odin data has been thoroughly validated and showed a good agreement when compared to several different data sets. The only possibility to find out if these differences are caused by uncertainties in the Odin/SMR data is to derive a 1-year data set from another globally measuring satellite. Such a comparison is intended for future studies, however, it is beyond the scope of this study. The text in the paper reads as follows: *To understand this difference in detail further data sets have to be taken into account. However, this is beyond the scope of this study. The same applies to the unusually high N_2O values found in the Odin/SMR monthly averages at $650 \pm 25K$ ($N_2O > 300$ ppbv). It has to be noted that the reported statistical uncertainty of single Odin/SMR data points on that level is of the order of the chosen N_2O bins size ($1\sigma \approx 25$ ppbv). This may lead to an artificial extension of the correlation curves at their ends. This argument is supported by the fact that a rather low number of data points is present in the bins for $N_2O > 300$ ppbv compared to other bins.*

Technical comments: (1) P1981 L26; P1982 L4; P1983 L12: The model simulations were performed for different time periods, however in our analyses we focused on simulation results for the year 2003. Solely, the CLaMS simulation is not entirely for the year 2003, but for the winter 2002/2003. Indeed, here we compare the November 2002 data from CLaMS with the November 2003 from Odin/SMR and the other models. However, as shown in our previous studies differences between different years are low. We included in this paper a figure comparing Odin/SMR data from 2003 with the two following years (2004 and 2005) to show this once again (see also our response to specific comment (1)).

(2) P1985 L25-P1986 L10: We included some numbers for the intercomparisons. The text reads now: *The intercomparison studies of Version 1.4 and Version 2 target species by Griesfeller et al. (2008) and Wetzel et al. (2008) show an improvement of the O_3 data in the northern hemisphere compared to the former Version 1.4 and a good agreement with*

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measurements from MIPAS-ENVISAT and the balloon-borne MIPAS-B, respectively, between 16 and 31 km. The differences between ILAS-II Version 2 and MIPAS-ENVISAT were about 0.3 ppmv (8–10%) while between ILAS-II and MIPAS-B mean differences of about -10.0% (Version 2) and -6.3% (Version 1.4) respectively, were found. Differences between the two retrieval versions were small for N_2O and a good agreement with MIPAS-ENVISAT and MIPAS-B measurements was found as well between 16 and 31 km. The largest differences between ILAS-II and MIPAS-ENVISAT N_2O were found at 13 km and 14 km with values of 0.04 ppmv (10%) and 0.05 ppmv (15%) for ILAS-II Version 2 and Version 1.4, respectively. Mean differences between MIPAS-B and ILAS-II were about -11% for both versions.

- (3) P1992 L21-22: The language has been improved.
- (4) P1993 L1: 'led' has been changed to 'lead'.
- (5) P1994 L19: 'this' has been changed to 'these'.
- (6) P1996 L11: 'a' between 'thus' and 'less' has been deleted.
- (7) P2001 L5: 'significantly' has been changed to 'significantly'.

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