

REPLY TO REFEREE #2 COMMENTS

I recommend publication after my comments are properly addressed.

Thank you very much for your time and evaluating the manuscript. Please find the revised manuscript and the answers for your questions and comments below.

General comments: – The method of calculating the ozone loss quantities from model simulations and observations is not sufficiently explained and discussed. If the ozone loss from observations is calculated as difference between the passive ozone tracer from the model and the observed ozone, how reliable is the result for the observations if the model transport and thus the passive ozone tracer has a bias?

The method of ozone loss calculation is mentioned in lines 180–203. Please note that the model has been used for ozone loss studies in different Arctic and Antarctic winters in the past. Previous studies with the model simulations indicate that there is no systematic bias in the model, although we find a clear underestimation of ClO and ozone here. The assessment of previous studies together with these simulations indicates that there is no constant bias pattern in the simulations, and the model-measurement differences vary with year and hemisphere. However, the presented simulations with the deficiency in the vertical descent in spring suggest that the measured ozone loss is underestimated. This has been mentioned in lines 450–469.

– It would be helpful if you include a figure of the temporal evolution of the (e. g. vortex averaged, or minimum) temperature for each year for the model simulations and the observations.

Done. Please find the new Figure 2 and Sect. 3.2.1.

– The description of the results is focused on the model simulations. Since you highlight the highly resolved observational data from “one of the best satellite instruments” in the introduction I expected a more detailed description of the measurements. Therefore I suggest reorganising the paper and starting with a description of the observed ozone loss, followed by the analysis if the model can reproduce the observations. However, if you decide not to change this because your main focus is on the model results, please point out more clearly why these simulations allow a new insight in this topic. And please address the following specific comments on this section.

As suggested, we have stated the importance of this study and how it allows new insights into this topic in lines 80–109.

– The section 3.3 “Interannual variations” is started with “Chlorine activation”. I think that since the main focus of this study is to analyse the interannual variability of ozone loss, it would be better to start with the analyses of the loss variability and explain the results with the help of the analysis of the chlorine activation and so on. If you decide not to change this, you have to give a short motivation in section 3.3 why you start with chlorine activation here.

We discuss the interannual variability of ozone loss in this study. In order to do this, we first examined the yearly changes in the meteorological condition and chlorine activation, and then tried to explain the ozone loss in each winter with respect to the extent of activated chlorine in those winters. This is the motivation for organising the sections in the aforementioned way. We hope that the reviewer will find it as a good decision. This has been mentioned in lines 267–282.

–Specific comments: Introduction: General: The introduction is very short. I think it would be worth

to include some more background information on ozone chemistry (e.g. chlorine activation,..) and dynamics for the southern polar region.

Done. Please find the additional paragraph in Introduction, lines 39—61.

– Line 72ff: “.. with such high resolution measurements with high spatial and temporal coverage ..”
: I suggest: with such high resolution measurements that have a high spatial and temporal coverage inside the Antarctic vortex.

Done. Please find it in lines 96—98.

– Line 83: Please include here “chemical transport model”: .. the Mimoso-Chim chemical transport model is used ..

Done. Please find it in line 110.

– Line 86: “.. average ozone loss evolution ..”: Which dimension is averaged? The time?

The average of ten winters. This is noted in line 115.

Simulations and measurements: – You start the model runs at 1 May and show the complete time series in the figures. Do the simulations need no spin-up time?

The simulations do not need spin-up time.

- Line 128: Is it H₂SO or H₂SO₄?

H₂SO₄. Please find it in line 161.

- Line 128ff: “In the denitrification module ..”: This sentence is hard to read. Please rephrase it!

Done. Please find it in lines 161—164.

– Line 134: Is there a reference for the Aura MLS version 3.3, that you use?

Yes, Livesey et al. (2011), mentioned in line 169.

– Line 134ff: Which time resolution do the measurements have?

There are about 3500 profiles per day, as mentioned in line 173.

Results and discussion: 3.1: - Line 155: Here you use the quantity “chemical loss” which is explained by “passive ozone minus ozone”. I think you should give a short explanation in section 2 what is meant with “passive ozone” and “ozone” and how the ozone loss is calculated for the model and the observations (see general comment and comment to line 187).

Done. These are explained in a new paragraph, lines 180—203.

– Line 155: In Fig. 1 this is already shown for May. In June levels above 450 K show an ozone loss different from zero in the model. Please write May here.

Done. Please find it in line 215.

– Line 159: “The loss increases again in August ..”: As far as I can see from the Figure, the loss increases in all EqLs from May to September. I think the word “again” is confusing. I suggest “The loss continues to increase in August ..”

Done. Please find it in [line 218](#).

– Line 166: “.. is found around 500 K ..”: The maximum is rather at 550 K than at 500 K

Done. Corrected in [line 225](#).

– Line 169: “ .. very large loss ..” Please remove “very”

Done. Please find it in [line 228](#).

– Line 171: As far as I can see from the Figure it is not the EqL range 75°-83°S but 77°-83°S that peaks in the middle stratosphere.

Done. Please find it in [line 230](#).

– Line 172: “.. it peaks in the middle stratosphere..” I suggest: “.: it peaks in the middle stratosphere (600K) ..”

Done. Please find it in [line 231](#).

– Line 174: “.. while other EqLs show their peak loss in the lower stratosphere, below 575K”. I suggest: “while other EqLs show their peak loss below 575K”

Done. Please find it in [line 232](#).

– Line 182: “.. show ozone losses below 500 K that are about the same as at 500 K.” This statement is imprecise since the loss below 450 K is clearly lower than that at 500 K. Please rewrite this sentence.

Done. We were discussing the ozone loss below 500 K in October here, for which all EqLs show more or less the same ozone loss with altitude. Please find the revised sentence in [lines 240–242](#).

– Line 187: What exactly is the cumulative ozone loss? Is it the cumulative loss over one day or month? Please note this in section 2 (see comment to line 155).

Ozone loss was computed as the passive model tracer *minus* ozone (measured or simulated). The “cumulative ozone” term was used to distinguish it from the instantaneous loss. To make it clear we have removed the term “cumulative” and used “ozone loss” as in the previous publications and similar analyses in the past. Please find the method of ozone loss calculation in [lines 180–204](#) and the revised statement in [lines 245–246](#).

– Line 189: What do you mean with the “normal” chlorine activation period?

Mid-June to mid-September is mentioned here and is noted in [lines 249–250](#).

– Lines 191ff: From Fig 1 I would rather state that the latitude dependency and evolution with time of the ozone loss in the model is below 500 K in good agreement with the measurements. I

suggest that you rewrite this passage.

Done. This has been modified with the altitude (500 K) information. Please find it in [line 254](#).

– Line 195: “.. and the model-measurement differences are relatively larger in September.”
Larger than what? Please rewrite this sentence.

Larger than that in other months, and is mentioned in [line 259](#).

– Line 197: “The ozone loss deduced from measurements..” This sentence is hard to read. I suggest:
The ozone loss of about 0.05-0.08 ppmv that is derived from the measurements in May at 360-370 K
is within the estimated error bars of the measurements and therefore insignificant.

Done. Please find it in [lines 261–264](#).

– Line 276: Is HCl not a large part of Cly? Why is Cly lower and HCl larger due to the slower descent?

Because of the slower decent, the HCl values are also relatively smaller (see the reply to Referee #1). This has been corrected in the text in [lines 358–364](#).

3.3. I suggest changing the title of section 3.3.1 to “Activated chlorine” .

Done. Please find it in [line 317](#).

– Line 234ff: “We have already discussed ..” I suggest: “We have discussed the general features of the observed and modeled ozone loss evolution in the Antarctic stratosphere as well as the related chemical cycles.”

Done. Please find it in [lines 268–269](#).

– Line 251ff: Chlorine activation depends not only on the temperature and the occurrence of PSC, but also on the available amount of chlorine reservoir species which can vary from year to year. You discuss this later to explain the results, but I suggest including this here as well.

Done. Please find it in [lines 328–332](#).

– Line 282: I don't understand why you tested the different rate since you explained earlier that the differences are caused by transport. Please explain this.

Done. We have tested different parameters/factors to identify the sources of model and measurement offset. Therefore, we have also checked the new rate constant as suggested by von Hobe et al.. Please find the revised sentence in [lines 378–383](#).

–Line 316: How do you define the “onset of ozone loss”? If the loss is larger than 1 ppmv?

Around 0.5 ppmv, as mentioned in [line 418](#).

–Line 331: Please remove “Relatively”

Done. Please find it in [line 433](#).

– Why is the observed ozone loss in 2007, a moderately cold winter (Line 340), larger than the observed ozone loss in the very cold winter 2005?

As illustrated in Figure 2, the minimum temperature at 500 K in 2007 in spring is lower than that of 2005. This could contribute to the higher ozone loss in 2007. This has been mentioned in lines 453—455.

– Line 349: Which years are meant here? In the observations the years 2006 and 2007 have the largest loss, however, in the model the 4 years 2005 to 2008 show similar large ozone loss.

The years 2005—2008 and 2011. This has been mentioned in line 452.

– I miss a statement about the year to year variability of the ozone loss. As far as I can see from figure 5, the difference between the largest maximum ozone loss and the smallest maximum ozone loss derived from observations is larger than shown by the model simulations. This means that the year-to-year variability is smaller in the model. I think this is an important result and should be discussed.

Done. This has been mentioned in lines 456—463.

– Lines 350-360: Here, you discuss that the model ozone loss is overestimated due to the slower descent in the middle stratosphere. However, since you use the passive tracer from the model to derive the observed ozone loss, I think, that the ozone loss derived from observations is underestimated. Please consider this in your discussion.

Done. Please find it in lines 464—467.

– Line 375: Why is the analysis of the partial column ozone loss important for this study? Do you expect new results or is it for comparison with other studies? Please motivate shortly at the beginning of the section why you included this analysis in the study.

Done. In this study, we perform a comprehensive analysis of ozone loss and related polar processing for the past decade. Therefore, in order to complete this analysis, we also made an assessment of the interannual variability of column ozone loss. This has been mentioned in lines 483—488.

–Line 446: Please change “model tracer” in “passive model tracer”

Done. Please find it in line 509.

– Table 2: I suggest including a figure with the information of table 2. This is more illustrative than the bunch of numbers.

Done. Please find the new Figure 6.

– Line 383ff: In 2006 the ozone loss in the 350-850 K region is smaller than in 2005 also from observations. Please rewrite this sentence.

Done. Please find it in lines 499—504.

–Line 418/19: Please remove “relatively”.

Done. Please find it in line 535.

-Line 447: Please insert "in the model simulations" in the first sentence of section 3.3.4

Done. Please find it in lines 561—562.

-Line 455: "natural" is not the correct word here. I suggest "photochemical".

Done. Please find it in line 572.

-Conclusion- Line 505-509: This sentence is too imprecise, since you always have a coldest winter in a ten year period. Please rewrite the sentence.

Done. Please find it in lines 622—626.

-Line 528: Please remove "relatively".

Done. Please find it in line 645.

-Line 540-542: Is this a new result?

We have removed the complete section.

- Line 545: ".. the Antarctic ozone hole will continue to occur for the next few decades.. " I think, this statement is too superficial, since you don't say anything about the extent of future ozone holes. Here, I would expect a statement to the actual discussion if the last years with small ozone hole areas already indicate a recovery or if this is rather an issue of variability.

Done. Please find the revised statement in lines 661—667.

-Figures: In general: You write "Potential Temperature/K " as well as "ppbv/sh" at the Y-axes. I suggest: Potential Temperature in K and ppbv/sh.

Instead of changing 4 figures, we have included this information in all figure captions. We hope that the referee will find it as an appropriate decision. Thank you.

-In the Figures 3-5 you show daily cumulative ozone loss. Why is the unit ppmv and not ppmv/day?

This is the ozone loss (passive tracer *minus* ozone), not the cumulative ozone. So the unit is in ppmv. We have removed the "cumulative" term now. This has been mentioned in lines 187—189.

-Why do you use a logarithmic Y-scale here, but a linear scale in Fig. 1?

The distribution of N₂O in the stratosphere is nearly exponential, as it has exponential decrease in its concentration from the lower stratosphere to middle and upper stratosphere. Therefore, the variations and differences are better illustrated with a logarithmic scale.

-Please add the information which altitude in km corresponds to 500K and 675K approximately.

Done. Please find it in the figure captions e.g. Figures 2—5.