

## REPLIES TO THE COMMENTS OF Marc von Hobe (REFeree)

The paper .... gives a detailed overview of the processes (dynamics, chlorine activation on PSCs/aerosol, catalytic cycles) leading to ozone loss at different times of the winter and in different altitude regimes. The manuscript complements other analyses of the unusual 2010/11 Arctic winter and makes a significant contribution towards understanding the interplay between the various processes leading to such extreme events of Arctic ozone loss. Complete understanding of these complex interactions is a prerequisite in order to recognize possible future effects of climate change on the stratospheric ozone layer in polar regions. I recommend publication in *Atmospheric Chemistry and Physics*, but suggest some clarifications and a few technical corrections described below.

### # Thank you for recommending publication.

#### *Minor issues:*

1. It is not entirely clear why you chose the winter 1996/97 for detailed comparison rather than another very cold winter or even a number of cold winters. There is one sentence in the introduction mentioning the long vortex persistence in 1997, and I can think of other reasons to choose this particular winter for the comparison, but would like to see a more elaborate rationale from the authors at the end of the introduction.

**# The temporal evolution of temperature and vortex was more or less similar in both winters as compared to other Arctic winters. The prolonged persistence of the polar vortex was remarkable in both winters. However, the chemical processes were different in these winters. So we thought both winters merit a close comparison in terms of their chemical and dynamical processing. We have mentioned this in the revised text in [Page 2, Paragraph 1, Lines 2–11](#)**

2. In last paragraph of the introduction, you merely list the headings of the sections and subsections rather than presenting further details or a rationale for structuring your manuscript in that particular way. The paper is also not unusually long, so I think you may not need this “written outline” at the end of the introduction.

**# This was inserted as per the suggestions from the Editor. However, we have slightly elaborated this text in [Page 2, Paragraph 2](#)**

3. In the last paragraph in Section 3.1, you mention the large size of the vortex 1996/97, but you also state that the 2010/11 vortex formed “with considerable size”. It may be worth mentioning that in the later half of the winter (February – April), the 2011 vortex was significantly smaller than the 1997 vortex (and the vortex in some other years) as was shown in Supplementary Figure 2 in the Manney et al. (2011) paper.

**# This has been reformulated in [Page 3, Paragraph 3, Lines 18–22](#)**

4. In Section 3.2.2, for the winter 2010/11, you discuss denitrification, while for the winter 1996/97 in Section 3.2.1 you do not. Is there a reason for doing so?

**# Yes. Denitrification in the Arctic winter 1996/1997 was studied extensively (e.g. Irie et al., 2001; Kondo et al., 2000; Santee et al., 1999; Mann et al., 2003). In addition, there was no large vortex-wide denitrification in this winter, as in the case of the colder Arctic winters 1999/2000 and 2004/2005 (e.g. Kleinböhl et al., 2005). Therefore, we haven't studied the denitrification in**

**1996/1997. This has been reformulated in [Page 4, Paragraph 1, Lines 12—16](#)**

Also it seems strange that the way chosen to order and present the Figures for the two winters (Figures 3 + 4 for 1996/97 and Figure 5 for 2010/11) is different.

**# Unlike in the case of Aura MLS measurements in the Arctic winter 2010/2011, the polar vortex coverage of UARS MLS or any other satellite (HALOE, SAGE, etc) in the Arctic winter 1996/1997 was not adequate and there were a number of data gaps, as shown in [Figure 4](#). Therefore, in order to give a complete picture of ozone, ozone loss and ClO inside the vortex for the winter 1996/1997, we had to present those from the model. On the other hand, the vortex averaged data from the model simulations and the model simulations at the Aura MLS foot prints were identical for the Arctic winter 2010/2011. Therefore, to avoid repetition in descriptions, we have presented the model simulations at the satellite sampling points inside the vortex for the Arctic winter 2010/2011.**

5. In the last paragraph of Section 3.2, please restructure the second sentence because it is hard to work out what number belongs to what scenario.

**# We have revised the text in [Page 4, Paragraph 6](#)**

Also, can you comment on the strong sensitivity of ozone loss towards NAT in your model being due to heterogeneous activation (NAT vs. binary aerosol) or due to denitrification (I suspect it is the latter)?

**#Yes, it is due to denitrification. This is stated in the text in [Page 4, Paragraph 6](#)**

6. In Section 3.3 (page 6888, line 5) there is a statement that “the model simulates comparatively higher abundances of NO<sub>x</sub> at altitudes above 550 K”. Does “comparatively” refer to 2011 vs. 1997? In that case, the supplementary figure does not support such a statement: the NO<sub>x</sub> contours look fairly similar for both winters. In fact, at least throughout April, the 2, 4, and 6 ppb contour lines are slightly shifted to higher altitudes in 2011 suggesting slightly less NO<sub>x</sub> than in 1997. Please clarify.

**# Yes, the NO<sub>x</sub> abundances at the higher altitudes in March—April 2011 are comparatively higher than those of 1997. Please find the elevated contours of 6, 8, and 10 ppbv in March—April 2011, as compared to those of 1997 (supplementary figure).**

7. The discussion on the winters 2003/4 and 2005/6 at the end of Section 3.3 comes a little bit “out of the blue”. In the figures and previous discussion, you don’t refer to these winters et all. If you keep the discussion, you should start with a statement, why these winters are special or noteworthy with respect to NO<sub>x</sub>.

**# In these winters there were additional ozone loss due to larger NO<sub>x</sub> descent from Mesosphere and thus, they merit a special attention. This has been stated in the revised text in [Page 5, Paragraph 4, Lines 10—24](#)**

*Technical corrections:*

1. Page 6878, Line 5: insert “of time” after period
2. Page 6878, Line 7: delete “simulations”. If you prefer, you could then also replace “Analyses” with “Simulations”.
3. Page 6878, Line 8: . . .started in early January. . .
4. Page 6879, Line 2: “In this region” doesn’t fit so well here. I suggest: “Since then, cold Arctic

winters are prone. . .”

5. Page 6879, Line 5: delete “often” (it’s redundant with the word “most” later in the sentence)

6. Page 6879, Line 24: delete “a” (simulations is plural)

7. Page 6881, Line 1: replace “simulated results” with “simulations”

**# All are corrected.**

8. Page 6881, Line 2: you use “ozone” several times before, so you may introduce the short O3 earlier.

**# We have changed this in some places.**

9. Page 6881, Line 17: “. . . at the Norwegian Institute. . .”

10. Page 6882, Line 4: “. . .to other cold winters. . .”

11. Page 6882, Line 12: “To check for sudden stratospheric warmings, . . .”

12. Page 6882, Line 22: “. . .which was about two weeks earlier. . .”

**# All are corrected.**

13. Page 6887, Line 5: you refer to Fig. 6a, not 6b here, right?

**# Correct. This has been stated in the revised text in [Page 5, Paragraph 1, Line 15](#)**

14. Page 6891, Lines 6-7: “. . ., we compare the results with the Antarctic ozone loss.”

**# Done. This has been stated in the revised text in [Page 7, Paragraph 1, Lines 3—4](#)**

15. Figure 1: legends and the description of colors and line styles in the caption are somewhat redundant (I would shorten the caption). And I do not see any dashed or dash-dotted lines mentioned in the caption.

16. Figures 3 and 4: Delete the last sentence of the caption (the color bars are enough).

**# Those were written by the suggestions from the Editor. So we have kept them as they are. We hope the referee will find it as an appropriate decision. [Figure 1](#): The dash-dotted line is in the temperature plot (top panel) and dashed lines can be found in the three panels at the bottom (zonal wind, heat flux and wave amplitude plots).**

17. Figure 8: for the comparison, it would be more helpful to have the lines for the Antarctic average in the same panel as the profiles from 2010/11 (but in a different color of course).

**# Done. Please find the revised [Figure 8](#)**

## REFERENCE:

Irie, H., Koike, M., Kondo, Y., Bodeker, G. E., Danilin, M. Y., and Sasano, Y.: Redistribution of nitric acid in the Arctic lower stratosphere during the winter of 1996/1997, *J. Geophys. Res.*, 106, 23 139–23 150, 2001.

Kleinböhl, A., H. Bremer, H. Kullmann, J. Kuttippurath, E. V. Browell, T. Canty, R. J. Salawitch, G. C. Toon, and J. Notholt: Denitrification in the Arctic mid-winter 2004/2005 observed by airborne submillimeter radiometry, *Geophys. Res. Lett.*, 32, L19811, doi:10.1029/2005GL023408, 2005.

Kondo, Y., Irie, H., Koike, M., and Bodeker, G. E.: Denitrification and nitrification in the Arctic stratosphere during the winter of 1996–1997: *Geophys. Res. Lett.*, 27, 337–340, 2000.

Mann, G.W., Davies, S., Carslaw, K. S., and Chipperfield, M. P.: Factors controlling Arctic denitrification in cold winters of the 1990s, *Atmos. Chem. Phys.*, 3, 403–416, doi:10.5194/acp-3-403-2003, 2003.

Santee, M. L., Manney, G. L., Froidevaux, L., Read, W. G., and Waters, J. W.: Six years of UARS Microwave Limb Sounder HNO<sub>3</sub> observations: Seasonal, interhemispheric, and interannual variations in the lower stratosphere, *J. Geophys. Res.*, 104, 8225–8246, 1999.

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