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Comment

# ***Interactive comment on “Chemical composition and severe ozone loss derived from SCIAMACHY and GOME-2 observations during Arctic winter 2010/2011 in comparisons to Arctic winters in the past” by R. Hommel et al.***

**Anonymous Referee #1**

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This study uses data products from the instruments SCIAMACHY and GOME/GOME2 to investigate the severe ozone loss in the Arctic winter 2010/11 as it was reported in several studies before. The evolution of the Arctic polar winter stratosphere is compared to other winters since 2002, with focus on the comparison with the winter 2009/2010. The observations of the trace gases BrO, NO<sub>2</sub> and OCIO are used to explain the special conditions in the winter 2010/2011 leading to the severe ozone loss in spring. BrO is used as indicator of horizontal mixing, NO<sub>2</sub> as indicator of denitrification and OCIO as indicator of chlorine activation. The chemically-induced ozone loss is cal-

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culated according to Sonkaew et al. (2013). The understanding of the processes leading to the observed ozone losses in 2010 and 2011 is tested with a three-dimensional isentropic chemistry transport model. Overall, this study confirms the results and explanations given in the literature. The large ozone loss in March 2011 can be attributed to the halogen driven catalytic cycles and the strong denitrification related to PSC occurrence. A difference to former studies is the detailed analysis of the ozone mini-hole situation in January 2011.

I find the article interesting and appropriate for the journal. It represents an update of earlier studies using the same observational data set and illustrates the large year-to-year variability in the Arctic polar stratosphere. However, it is required that the authors point out the main goals and the new findings of this study more clearly. There are many different analyses in this study but it is often not clear to me why these analyses are important and what the main message is. It would be helpful to give short conclusions for the different parts in order to highlight the gain of information obtained by the different analyses. Considering the length of the manuscript I suggest that in favor of a clear description of the new aspects, the discussion of some details (that are not relevant for the overall conclusions) should be shortened. I recommend publication after my comments are properly addressed.

Specific comments:

Title: An important part of this study is the detailed analysis of the mini-hole event. Maybe this should be part of the manuscript's title rather than the comparison to Arctic winters in the past?

16598 (Abstract): You mention the chemical transport model. What about results? Are the special conditions in 2011 reproduced by the CTM?

16599-16600: Can you identify the large denitrification and chlorine activation (as noted in the Introduction) in March 2010 in your data set (OCIO and NO<sub>2</sub>)? And how is this explained in a winter that you classify as a “warm” winter? You give some informa-

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tion about the conditions in the year 2010, but they are spread all over the manuscript. Maybe you can shortly discuss the year 2010 conditions also in section 3.7 and explain how the large denitrification matches to the “warm winter” and the high ozone levels.

16610, line 11: In Figure 2a no information about the year 2007 is given. I guess this must be 1995/1996. Furthermore, I would identify the record low in the year 2011 around day 80 and not 50.

16610, line 15ff: You should specify the “winter mean”, at least in the figure description.

16610, line 21ff: “Planetary wave activity during Arctic winter 2010-11 was among the lowest in the NH (..)” Here, you can include the reference Hurrwitz et al., 2011

16611, line 13: "In March 2010 and 2011 (..) with minimum ozone found above the North Atlantic sector between Greenland and Scandinavia. (..)" I can see this for 2011, but for 2010 the statement is not really appropriate. Please rewrite!

16613, line 25: “The BrO vortex averaged time-series of Fig. 5 are giving us the impression that in the depicted period 2011 the BrO variability was somewhat larger than in 2010.” For me this is hard to see in Fig. 5. If this is a relevant result, please verify your statement. Otherwise I suggest that you remove this sentence.

16614, line 6: Here, you argue that the decrease in BrO in April is caused by mixing of BrO poor air from the midlatitudes into the vortex (also 16619, line 7). Later (16619, line 9), you used BrO as indicator of mixing and state that the lower BrO levels in 2011 compared to 2010 are “due to slower large-scale meridional transport from the regions of its photochemical production.” Can you explain this discrepancy?

16615, line 9ff: You ask the question “Why this is influencing an isentropic ozone loss estimate, developed to infer the strength of the chemically-induced polar ozone destruction independently from reasons related to the dynamics of the atmosphere”, but in my opinion you don’t answer it clearly in section 3.8. Is the chemically-induced ozone loss during the mini-hole event unrealistic? Or does it represent the contribution

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from enhanced PSC occurrence and chlorine activation due to the adiabatic cooling? If there is enhanced PSC occurrence (see Fig. 9), why is it not possible that there is a chemical ozone loss in the illuminated part of the vortex? You should consider this for your discussion later on.

16616-17, a general question to section 3.4: If you compare the differences between the year 2010 and 2011 in your solar occultation data set, do you get the same conclusions as for the limb measurements?

16617, line 11-24: In your discussion you explain that you would expect lower BrO and larger NO<sub>2</sub> mixing ratio in occultation measurements compared to limb measurements. However, you observe larger mixing ratios in both gases. How can you explain the discrepancy in what you expect and what you observe?

16618, line 12: Here, a short conclusion of the relevant information that is obtained by analyzing the occultation measurements, would be helpful.

16618/19, general comment on section 3.5.1: In this section you compare the model results and the observations. However, in between you don't discuss differences between the model and the observations, but between the years 2010 and 2011. This is confusing.

16619, line 11-15: Here, you explain that the modeled BrO mixing ratios above 475K are larger in 2011 than in 2010 because of lower modeled NO<sub>2</sub> mixing ratios and a reduced formation of BrONO<sub>2</sub>. The question arises why this is only true for the model and not for the "real" atmosphere where also lower NO<sub>2</sub> mixing ratios are observed in 2011 compared to 2010. In the lines 16-22 you explain that the model underestimates the NO<sub>2</sub> mixing ratio which answers the question above. Therefore, I suggest that you reorganize the second part of section 3.5.1.

16619-20: To avoid confusion later on, I would suggest that you discuss the difference between the calculated ozone loss in the model and in the observations in the

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beginning of section 3.5.2 before the results are compared.

16621, line 20: In Figure 9 I can't see the maximum on 22 March 2011. It must be 22 February 2011.

16622, line 11ff: You don't need to use the "type I, a, b and II" term, just write NAT, ice clouds etc. Furthermore, if you use the abbreviations NAT and STS, you should explain them.

1622/23: Please shorten the discussion to the information that is relevant for your study.

16630, line 11: ".. and much larger ridge of tropospheric air .." -> larger than what?

16633, line 6-11: You state that the OMH-like situation has a direct impact on the chemical ozone loss later in spring. In Figure 9 however, the PSC occurrence rate decreases after this event and is in the range of other winters in the beginning of February. Furthermore, I cannot detect an impact on the chlorine activation in Figure 10. There is a steadily increasing OCIO mixing ratio averaged within the vortex and the variability is too large to identify a clear change in the time evolution during the OMH situation. Please explain in more detail how you come to this statement.

16633, line 12-16: You explain that the short-term BrO decrease is caused by the "thinning effect" of the OMH-event. What about the transport and mixing of air from the mid-latitudes? Would this reduce the "thinning effect"?

16633, line 20-22: No comparable ozone loss in the polar stratosphere will be expected, when the stratospheric chlorine loading has reached the natural background level, even if the occurrence of PSCs will increase. But in the first half of the 21st century, when the chlorine amount is still high, this might be relevant. I suggest that you rewrite the part "even when the ozone layer recovers to values of the pre-CFC era".

16636, line 7ff and in general: "(..) there are several detailed issues to be resolved (..)" Did you learn new details about the model performance? It seems to me that you

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already knew the deficits of the model before.

16636, line 10: “Finally, the observation of a large OMH coupled to a large Northern Hemisphere polar ozone hole is not a coincidence.” You should be more careful with this statement. You have argued that this OMH event could have triggered the severe ozone loss in March 2011. This may be true for 2011 (even if it’s hard to verify). However, even if the ozone loss in spring is larger with a preceding OMH event, a OMH event will not necessarily lead to a large ozone loss. Furthermore, you have to keep in mind that you have only one example and no statistically significant proof for this connection. You should write it as a hypothesis and not as a proven fact.

Technical corrections:

In general: You mix British and American English. Please unify the orthography. Different acronyms for polar stratospheric clouds are used (PSC or PSCs). Please unify this and introduce the acronym only once. UKMO, MIDRAD, LINOZ, .. is not introduced when it is used the first time.

16605, line 24: More detailed information on the PSC detection method can be found in von Savigny et al. (2005a). Repeated in line 11, 16606.

16606, line 18: “(..) references spectrum (..)” -> reference spectrum

16606, line 21: I suggest writing “(..) merged O3 total column data set, retrieved (..)”

16607, line 1: Remove "having"

16607, line 8: “(..) that extends from 1978 to present which agrees to within 2 % with (..)” Better two sentences: “..to present. It agrees within 2 % with ..”

16609, line 28: “below 80°N” -> south of 80°N

16610, line 4: “Results and Discussion”. I suggest that you entitle this section "Results".

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16610, line 23: “(..) heavily perturbed Antarctic ozone hole (..)” -> Maybe better: “perturbed Antarctic vortex”

16610, line 20-24: “Planetary wave activity during Arctic winter–spring 2010/2011 was among the lowest in the NH in the thirty years of satellite data (..) As a result, ozone transport from its source (...) was weaker in the second half of 2010 than in other years.” The second half of 2010 is July – December. Strictly speaking the ozone transport in summer and autumn 2010 is not a result of the planetary wave activity in winter-spring 2010/11. Please rewrite this sentence accordingly.

16611, line 4: “that” -> this

16611, line 16: “(..) was very high, an effect (..)” -> Two sentences: (..) very high. This effect is ( .. )

16612, line 6: “(..) with the two instrument’s data (..)” -> Maybe better: “with the data of the two instruments”

16613, line 7: Remove “being”.

16614, line 6: “In April of the two years (..)” -> Maybe: “In both years in April (..)”

16614, line 13: NO<sub>x</sub> should be specified here and not on page 16615.

16614, line 14: “NO<sub>x</sub>, and hence NO<sub>2</sub>, will (..)”

16615, line 2ff: (..) in April 2011, relative to values measured the first day of the year (..) . Please add “ozone” (“relative to ozone values”) otherwise the “values measured” are related to the loss.

16615, line 27: “on the order of” -> in the order

16617, line 2: “White limb dots mark measured profiles outside the vortex, those considered in the vortex-averages are marked in black.” The description of Figure 7 says however: “ (..) Limb measurements lying within the vortex are shaded dark grey .”

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Please unify. Furthermore, the small and large dots in Figure 7 are hard to distinguish, maybe due to the light grey frame? What does the color code of the large dots mean? Some of the measurements clearly don't lie within the vortex, but are still dark grey shaded. Please clarify this.

16617, line 8/9: "(..) are concentrated near the pole, thus only a few limb profiles capture (..)"

16617, line 19: anticorrelated or anti-correlated

16617, line 27: "Although the variability (..), but the low ozone period (..)". After "although" I would not expect a "but". Please rewrite this sentence!

16619, line 20: Please use quotation marks: "Noxon cliff"

16620, line 6: "They compared to loss estimates ..": Remove "to".

16621, line 10-16: This is a bit confusing. First you discuss the PSC occurrence in January 2010. Then you state that the total supply of PSCs was larger in 2011 than in 2010. Then you note that in 2010 the occurrence rate was 20% larger, but only during a short period. And at the end you explain that in 2011 the PSC period was longer than in 2010. It would help the reader, if you rewrite this part and discuss first the conditions in 2010 and then compare it to 2011 and avoid switching between the years.

16621, line 22: "Not exactly similar to the periods seen by SCIAMACHY, but largely overlapping." This is only a fragment of a sentence. Please rewrite.

16622, line 10, 16: The English word "information" does not have a plural form!

16622, line 12: "stated" -> "started"

16624, line 19: "no sign of increase in NO<sub>2</sub>" -> no increase in NO<sub>2</sub>

16625, line 14ff: "(..) similarly as the long-lasting low ozone period in March and April 2011. However, even if enough ODS (..)." "Also, why then should .." -> Furthermore,

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it cannot be explained by ozone chemistry why ozone recovers a few days later at approximately (...)

16630, line 6: “.. as id did not emerged ..” -> as it did not emerged

16631, line 23/24: “(..) behavior number densities, (..)”?

16632, line 18: “This led to a situation that (..) “ -> Maybe better: “Thus a larger area of the vortex was illuminated by the sun and hence observed (..) compared to a polar centred vortex. ”

16634, line 4: “(..) by employing the vortex-average technique (..)” I think, more important to note for the calculation of the chemically-induced ozone losses is that you use the diabatic descent rates.

16636, line 3-5: “To understand the chemical composition of the Arctic stratosphere improves our knowledge (..)“ -> “The understanding of the chemical composition..”

16647: If possible change the colors for the years 1995/96 and 1996/97 for a better distinction of the curves.

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Interactive comment on Atmos. Chem. Phys. Discuss., 13, 16597, 2013.

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