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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Polar processing in a split vortex: early winter Arctic ozone loss in 2012/13" *by* G. L. Manney et al.

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Referee comments are *italicized*; authors' responses are in regular (upright) text.

Anonymous Referee #2

Manney et al. present a study on the Arctic winter 2012/2013, a winter that was characterized by early winter polar processing and strong ozone loss resulting from the combination of unique dynamical conditions associated with a stratospheric warming in January 2013. Large ozone loss was observed during December and January, which was much larger than previously observed during these months. Nitric acid abundances were also among the lowest in the MLS record for the Arctic, indicating that the stratosphere has been denitrified. ClO enhancement during this winter was also

much greater than in any other Arctic winter observed by MLS. This shows that this winter was indeed one of the unique winters during the past decade. This study is very interesting and deserves to be published in ACP. I only have the following suggestions for (minor) revisions which should be considered before publication:

We thank the referee for their helpful comments. Our responses are interspersed below.

Specific comments:

Title: You mention ozone loss, but in fact many more processes than just ozone loss during this winter are analyzed (denitrification, chlorine activation etc.). So, I would suggest to change the title slightly to point this out more clearly.

Both "Polar processing" and "ozone loss" are in the title (in fact, "Polar processing" begins it) – we believe "Polar processing" conveys the occurrence of those other processes. We have, however, changed the "short title" for the running head to "Early winter polar processing in 2012/13" to reflect the multiplicity of processes that were taking place.

Abstract: In my opinion, the abstract is too long and too detailed and could be shortened to make it more concise. It takes too long until the authors come to the point why their study is of importance. I wasn't aware that this winter was so special And was quite confused why this winter was analyzed until I reached the end of the abstract. I would suggest to move this sentences higher up, so that they occur rather at the begin of the abstract than at the end.

We have condensed the abstract (per suggestions from both referees) and reorganized it along the lines suggested here; it is now one paragraph and just over 300 words (down from about 470). The revised abstract is as follows:

"A sudden stratospheric warming (SSW) in early January 2013 caused the Arctic polar vortex to split and temperatures to rapidly rise above the threshold for chlorine acti-

vation. However, ozone in the lower stratospheric polar vortex from late December 2012 through early February 2013 reached the lowest values on record for that time of year. Analysis of Aura Microwave Limb Sounder (MLS) trace gas measurements and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) polar stratospheric cloud (PSC) data shows that exceptional chemical ozone loss early in the 2012/13 Arctic winter resulted from a unique combination of meteorological conditions associated with the early January 2013 SSW: Unusually low temperatures in December 2012, offspring vortices within which air remained well isolated for nearly a month after the vortex split, and greater than usual vortex sunlight exposure throughout December 2012 and January 2013. Conditions in the two offspring vortices differed substantially, with the one overlying Canada having lower temperatures, lower nitric acid (HNO_3), lower hydrogen chloride, more sunlight exposure/higher ClO in late January, and a later onset of chlorine deactivation than the one overlying Siberia. MLS HNO_3 and CALIPSO data indicate that PSC activity in December 2012 was more extensive and persistent than at that time in any other Arctic winter in the past decade. Chlorine monoxide (ClO, measured by MLS) rose earlier than previously observed and was the largest on record through mid-January 2013. Enhanced vortex ClO persisted until mid-February despite the cessation of PSC activity when the SSW started. Vortex HNO_3 remained depressed after PSCs had disappeared; passive transport calculations indicate vortex-averaged denitrification of about 4 ppbv. The estimated vortex-averaged chemical ozone loss, $\sim$0.7–0.8 ppmv near 500 K ($\sim$21 km), was the largest December/January loss in the MLS record from 2004/05–2014/15."

P4974, L6: Please give a temperature for the chlorine activation threshold.

While we believe this information is important to provide in the text, and the values used as a function of pressure are discussed in the methods section, we feel that adding this interrupts the flow of the abstract, and is more detail than is appropriate for an abstract (particularly when our abstract was already too long and detailed).

P4974, L8: That would mean that the vortex was located quite far in the south. Can

you be more precise? Were exactly was the vortex located. How far south did the vortex reach?

Again, we feel this is detail that, while shown very specifically in the body of the paper (Figure 11), breaks up the flow of and adds to the length of an already long abstract.

P4974, L9-10: In case of MLS first the long name is given and then the abbreviation. In case of CALIPSO it is vice versa. I would suggest to do this consistent throughout the paper, either first the abbreviation and then the long name or vice versa.

All cases have been changed to long name (abbreviation).

P4974, L21: Is 4 ppbv much? Does that mean it was a strong denitrification. I would suggest to point out more clearly what this means.

To our knowledge, the amount of denitrification in the other years discussed here (2009/10 and 2010/11) when it was substantial has not been quantified from observations. It is very difficult to do so, since HNO_3 decreases in winter are typically partly because of temporary sequestration in PSCs, and decreases in late winter to spring result partially from photolysis. In fact, it was the unique situation of denitrification in 2012/13 occurring early and the signal persisting (in the confined offspring vortices) well after there were no longer PSCs, but before photolysis was significant, that allowed straightforward quantification of denitrification. Thus this question is not only too complex to address in the brief summary in the abstract, but is in fact well beyond the scope of the paper itself. We have, however, added a comment on the difficulty of assessing denitrification in the presence of sequestration in PSCs and/or significant photolysis, and thus the inability to compare quantitatively with 2009/10 and 2010/11, on page 4996, around line 13, where we compare qualitatively with those years.

P4974, L1-26: As mentioned above, reading the first paragraph of the abstract without being aware how special this winter was, I did not understood it and was wondering why this study was performed. Of course, I realized that there must have been something

special, but I wasn't sure what. The questions that came up in my mind was: What is so special with this winter? Was it the split, the unusual long exposure of the vortex to sunlight or the high chlorine activation?

It was the combination of the vortex split, the exceptional cold in December and the unusual exposure to sunlight. We believe that the revised abstract shown above clarifies this.

P4974, L28: Please add the CALIPSO observation period.

The duration (so far) of the MLS and CALIPSO observation periods is given in the revised abstract.

P4975, L24-31: As mentioned above I would suggest to move these sentences up.

The abstract has been reorganized as shown above, with this information now near the beginning.

P4975, L26: I would appreciate if also other publications discussing Arctic ozone loss during the 2010/2011 winter would be cited, as e.g. the publications by Sinnhuber et al. (2011), Kuttipurath et al. (2012), Arnone et al. (2012), Hommel et al. (2014).

We have added these references here, as well as the 2014 WMO report (which has numerous other references discussing this winter), along with "and references therein".

P4977, L24: Same comment as above; first the abbreviation or the long name?

All cases have been changed to long name (abbreviation).

P4978, L10-11: First the abbreviation and then the long name or vice versa as mentioned above.

All cases have been changed to long name (abbreviation).

P4978, L10: Is the usage of the abbreviation G591 for the GEOS data really necessary? I would suggest to just call it GEOS or GEOS-5 (or even GEOS-591 if you prefer

to use the version number).

We believe the version number is needed to distinguish it from the GEOS-5.2.0-based MERRA data that we also use/discuss. However, we have changed the references to it to "GEOS-5.9.1".

P4979, L1-2: The link to the web page could be given as footnote.

This has been replaced with a standard reference suggested by referee 1.

P4981, L16: see my comment on page/line P4978, L10.

See response to that comment.

P4982, L7: As mentioned in one of my previous comment other studies showing the severe ozone loss during the Arctic winter 2010/2011 deserve to be cited as well. Especially, it would be worth to mention the most recent ones as e.g. Hommel et al. (2014) since they usually cite all earlier papers dealing with this winter.

We have added the Hommel et al (2014) citation here, along with the 2014 WMO report and "and references therein". This and the other suggested references were also added in response to the previous comment.

P4982, L28: The study by Achtert and Tesche (2014) published in JGR should be cited here as well.

This reference has been added as suggested.

P4983-4984: This may be a matter of taste, but I am not very fond of introducing and using too many abbreviations. I do not see any benefit of the abbreviations DMP and LTD, especially since e.g. DMP occurs in the text only twice and LTD only four times.

These names are now spelled out wherever they are used.

P4985, L14-15: "an animation covering..." I would suggest to put this sentence either in brackets or in a footnote.

This has been changed to a parenthetical comment.

P4989, L25 and P4990, L1: As stated above, I am not fond of too many abbreviations. Is the abbreviation VTC really necessary and useful?

This is now spelled out each time it is used.

Section 4: In this section the many different gases and chemical processes are discussed. Wouldn't it be possible to divide this section into subsections to make this section more clearly represented?

We believe showing each view of multiple trace gases together is important to demonstrating the connections between the processes affecting each, so to divide it by trace gases would detract from the message. However, recognizing the length and density of the section, we have divided it into three subsections entitled "Overview and average trace gas evolution" (encompassing descriptions of Figures 7 through 10), "Trace gas evolution in the offspring vortices" (Figure 11 and discussion thereof), and "Comparison with other Arctic winters" (Figure 12 and discussion thereof). We hope that this helps to more clearly focus attention on each of these three key topics in the section.

P4997, L22: What trajectory methods?

We now state "the reverse trajectory and Lagrangian trajectory diagnostic methods described in section 2.3.3" to clarify this.

P4997, L25: What is the abbreviation "RT" standing for? Maybe you introduced it already somewhere in text earlier, but until I came to this paragraph I already have forgotten what is was standing for.

This is spelled out and defined again here, with a reference back to section 2.3.3 where it is first defined.

P5000, L17: The SSW is the cause for the vortex split. This should be clearly stated.

"the vortex-split SSW" has been changed to "an SSW that split the vortex" to clarify

this.

P5000, L21: see my comment on page/line P4978, L10.

See response to that comment.

P5002, L17: Please add the MLS observation period considered in this study.

This information has been added.

Technical corrections:

P4994, L 9 and 10: Add "N" so that it reads 60N and 50N, respectively.

Done.

Figure 12 caption: Shouldn't it rather read "for the other Arctic winters..." than "for the other years..."?

Changed as suggested.

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 4973, 2015.