Response to Anonymous Referee

Can the authors give an estimation about the influence of the type of this specific 2009 MW (vortex split) on the results? Is it possible to generalise the results, i.e. is the analysing method (tracer-tracer correlations) sensitive enough to be applicable also to MWs which are less intense than the exceptionally strong 2009 MW?

It is possible and even easier to apply tracer-tracer correlations on a less intensive MW. Because the main difficulty of analyzing tracer-tracer correlations is distinguishing the dynamical effect (advection and mixing) from chemistry (e.g. chlorine-induced ozone loss, NO_X chemistry). A winter with stable and cold polar vortex (or with a less intense warming) indicates less transport or mixing across the transport barriers, which is favorable for the compact tracer- tracer correlations and thus the chemistry effect is possibly dominant. In fact, ozone -tracer relation have been used extensively to estimate ozone loss (e.g., *Proffitt et al.*, 1990; *Müller et al.*, 1996, 2001; *Tilmes et al.*, 2006). However, the intensive 08/09 MW case is an example that dynamics and chemistry is mixed up in tracer space. Therefore, special attention should be paid on applying tracer-tracer correlations. In this sense, a chemical transport model with explicit mixing process will help us to understand the details of the tracer-tracer correlations.

In order to explain this point better and also following the other referees' recommendation, we revised considerably the introduction and Section 5. One schematic (new Fig. 1) was added to the introduction. This figure and its corresponding text give the background of tracer- tracer correlation before further discussion. Then section 5 was re-organized in to four subsections: N_2O-O_3 correlations: MLS versus CLaMS; tracer and physical space; isentropic mixing versus cross-isentropic transport; impact of chemistry. To achieve the consistent translation between physical space and tracer correlation space, the Figure 8 is extended: the physical space interpretations are added to the corresponding tracer correlation.

Specific comments

- *Page 4386, line 8:*
  Your description of atmospheric transport refers to the modelling perspective of this process. This should be emphasised in this context.
  We modified the paragrapg.
  See L.65-68 on Page 3.

- *Page 4386, line 6:*
  Are the result of Sofieva et al. (2012) related only to a specific MW (if yes, which one?), or are these results obtained by analysing several MWs?
  Sofieva et al. (2012) studied four SSWs (2002- 2003, 2003- 2004, 2005- 2006 and 2007-2008) and three SSWs (2003 Jan, 2004 Jan and 2006 Jan) met the criteria of MWs.

- *Page 4388, lines 4-6:*
  Unlike you have stated, a negative temperature gradient between the North Pole and 60°Nat 10 hPa is characteristic for an undisturbed polar vortex. This situation is present during the second half of December 2008 and the first half of January 2009.

  You should start with a more general statement about the stratospheric winter 2008/09, instead of starting with a sentence about the Minor warming, which is present during the first *week of December 2008, indicated by a slightly positive temperature difference between the North Pole and 60°Nat 10 hPa and a deceleration of the stratospheric jet.*

We agree. The description of minor warming is "second order" information and somehow miss-leading. And another reviewer also pointed it out and suggested us to clarify the definition of major SSW here. Therefore, we rewrote the paragraph with a general statement: major SSW criteria we used and the central date identification.

- *Page 4391, lines 19-23:*

  description of model runs; You should try to reformulate this section, to clarify your experimental setup. As far as I understood this paragraph, you performed two simulations with CLaMS, one with mixing and one without mixing. Both simulations are performed with full chemistry, and in both simulations, besides the ozone calculated with full chemistry, also a passive ozone tracer is present.

  Or have there been four different CLaMS simulations: two sets of simulations, first set (full chemistry) with mixing and without mixing, second set (passive ozone tracer) with mixing and without mixing.

  A table, summarizing the experimental setup with unique labels for each simulation would be helpful. Using these labels consequently in section 5 could help the reader to better follow your argumentation.

  The two simulations both with O_3 as passive tracers are performed in our studies. The difference of these two runs is including mixing or not. To say it more clearly, we revised the last paragraph in Section 3.1.

- *Page 4395, line 6:*

  Please give a short description of the Nash criterion here.

  The description of the Nash criterion is added here and also in Figure 4 caption. See L.300-303 on Page 9 and caption of Fig. 4 (original Fig. 3).

- *Page 4402, lines 8-11:*

  chlorine induced ozone loss; More explanation is needed here to follow your argumentation. Figure 7a (situation from December 18-28) and 7b (situation from January 18-28) both display situations during mid-winter. How can these figures be used to analyze the chlorine induced ozone loss, mainly occurring in late winter and spring?

  Firstly, the new Fig. 1 (c) might be helpful to illustrate how to use ozone- tracer correlations to examine polar ozone loss. Secondly, the chlorine driven polar ozone loss usually happens in the late winter and early spring within a sufficiently cold polar vortex. However, a new study by *Manney et al.* (2015) has confirmed that the ozone loss was significant due to the unusual low temperature in the lower stratospheric polar vortex before the MW (mainly in December and January) in a very similar strong MW winter (2012/13). Some changes has been included in the Section 5.4 about this point.

Technical corrections

- *Page 4385, line 26: insert article; ... over the Pacific.*
  Article is inserted.

- *Page 4385, line 26: delete article ; ... before the MW and strongest after ...*
  Article is deleted.

- *Page 4386, line 1: delete article ; ... trend of occurrence of NH MWs ...*
  Article is deleted.

- *Page 4388, line 11: insert article; ... the sudden rise of the polar cap temperature ...*
  Article is inserted.

- *Page 4388, line 16: insert article; ... while the disturbance of wind and temperature ...*
  Article is inserted.

- *Page 4389, line 12: Correct the unit for the eddy heat flux to K m* s^{-1}
  Corrected.

- *Page 4389, line 13: date format changes; Change 6 January to January 6. Also change the date format in line 13 and 14 on the same page and at subsequent pages, to be consistent.*
  Changed.

- *Page 4395, line 1: correct; ... stable vortex ...*
  Changed.

- *Page 4417, text displayed within figure 5: To make the information more readable please plot the text within figure 5 in white*
  Changed.

References

Manney, G. L., Z. Lawrence, M. Santee, N. Livesey, A. Lambert, and M. Pitts (2015), Polar processing in a split vortex: Arctic ozone loss in early winter 2012/2013, *Atmospheric Chemistry and Physics*, *15*(10), 5381–5403.

Müller, R., P. J. Crutzen, J.-U. Grooß, C. Brühl, J. M. Russell III, and A. F. Tuck (1996), Chlorine activation and ozone depletion in the Arctic vortex: Observations by the Halogen Occultation Experiment on the Upper Atmosphere Research Satellite, *J. Geophys. Res.*, *101*, 12,531–12,554.

Müller, R., U. Schmidt, A. Engel, D. S. McKenna, and M. H. Proffitt (2001), The O_3–N_2O relationship from balloon-borne observations as a measure of Arctic ozone loss in 1991/92, *Q. J. R. Meteorol. Soc.*, *127*, 1389–1412.

Proffitt, M. H., J. J. Margitan, K. K. Kelly, M. Loewenstein, J. R. Podolske, and K. R. Chan (1990), Ozone loss in the Arctic polar vortex inferred from high altitude aircraft measurements, *Nature*, *347*, 31–36.

Sofieva, V., N. Kalakoski, P. Verronen, S.-M. Päivärinta, E. Kyrölä, L. Backman, and J. Tamminen (2012), Polar-night O_3, NO_2 and NO_3 distributions during sudden stratospheric warmings in 2003–2008 as seen by gomos/envisat, *Atmospheric Chemistry and Physics*, *12*(2), 1051–1066.

Tilmes, S., R. Müller, A. Engel, M. Rex, and J. Russell III (2006), Chemical ozone loss in the Arctic and Antarctic stratosphere between 1992 and 2005, *Geophys. Res. Lett.*, *33*, L20812, doi:10.1029/2006GL026925.