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Atmospheric Chemistry and Physics Discussions

# *Interactive comment on* "The major stratospheric final warming in 2016: Dispersal of vortex air and termination of Arctic chemical ozone loss" *by* Gloria L. Manney and Zachary D. Lawrence

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This paper provides a thorough description of the evolution of the 2015/2016 Northern Hemisphere stratospheric winter until the breakup of the polar vortex and the dispersal of its fragments. This winter was unique: while it initially presented the characteristics for an unprecedented ozone loss (i.e. prolonged temperatures below ice polar stratospheric cloud thresholds), an anomalous early and strong major final warming interrupted the ozone depletion process. Dynamical and chemical processes are characterized using Microwave Limb Sounder satellite trace gas measurements, and advanced mixing and polar vortex diagnostics derived from meteorological reanalysis.

This case study of the winter 2015/2016, and its comparison with the series of singular



recent winters, very well illustrates the complexity of the dynamical and chemical interactions that drive Arctic ozone depletion. In my opinion, this paper is important as it further contributes to showing that each Arctic winter season is unique and that substantial research efforts are needed to better understand their extreme variability and the consequences of this variability (e.g. on ozone depletion, stratosphere/troposphere couplings, ...). The methods and diagnostics used in this study are scientifically sound and relevant. The analysis is very carefully conducted. My main criticism rather concerns the form: the main text and its figures are extremely dense and contains a lot (too much?) of information so that it is sometime hard to differentiate what is important from what is more anecdotal. While in some places the degree of detail seems to me exaggerated (e.g. p10l32-p11l10 where tracer extrusions are discussed while not really obvious), in other places, including further details may help to make the paper easier to follow (see comments below). Hence in my opinion, this paper is suitable for publication in Atmospheric Chemistry and Physics after consideration of the specific (minor) comments and suggestions provided below.

Specific comments:

1) p3l32: Typo change "MERRRA" to "MERRA"

2) p4l20: Please provide further detail on the way the potential vorticity is scaled. The sPV is widely used throughout the paper so few precisions about it may be useful for the readers.

3) Diagnostics (i.e. sections 2.3 & 2.4): This paper makes use of a very high number of diagnostics to describe mixing processes, transport, vortex size and so on. Although the different diagnostics are very well explained in the main text, non-expert reader may quickly be lost once the description of the (dense) analysis begins. The authors may consider adding a table which gives a summary describing (briefly) the different diagnostics and their usefulness.

4) p7l25: "The 2010/2011 winter ...". Please mention the associated color line in

bracket to help the reader.

5) p8l1: “In early January 2013 . . .”. Same here, please mention the associated color.

6) p8l2: “. . . strongest “vortex-split” SSWs on record. . .” What does strong mean here? What defines the strength of a SSW (persistence, temperature, vertical extension, . . .?)? Please clarify.

7) p8l6: “2014/2015. . .”. Please mention the associated color.

8) p8l6: “. . . brief minor SSW . . .”. Please give the date. (I guess early January)

9) p8l13: Typo change “though” to “through”

10) p8l14: “unprecedented”. On MERRA record? Please clarify.

11) p8l31: “. . . in 2015/1016, 2012/2013, and 2010/2011 . . .”. Why not 2014/2015? The green curve looks similar in early winter on Figure 2a.

12) p11l1-2: “This is consistent [. . .] anticyclone during this period”. Does anticyclone refer to the Aleutian High here? Please clarify.

13) Figure 8: Please replace y-axis “Effective diffusivity” by “Keff” to be consistent with the main text (p11l30).

14) p11l33: “. . .Keff and M minima. . .” Is it not rather M maximum? M maximum $\Leftrightarrow$ vortex edge $\Leftrightarrow$ transport barrier.

15) Figure 9-14: Please make the continents more visible on maps and provide at least on longitude coordinate. Otherwise it is quite hard to follow Figures together with the main text and the geographical location that are refereed (e.g. Alaska p13l7 but also at other places).

16) P13l12: “. . . in the anticyclone.”. Is it not “. . . in the edge of the anticyclone” that the M values are the strongest?

17) At 550 K, a doubled vortex edge appears in the main vortex fragment (see Fig 11,



14) from beginning of April. Is this an artifact or a real structure? Please comment on this.

18) Figure 13-15 (and associated text). The green and blue offsprings seem actually switched between the 490 and 550 K levels. If indeed this is the case, it may be confusing. Therefore, it may be more relevant to keep the same color for the upward extension of the same offspring.

19) p15l17-19: May this vortices coherence dependence with height be partly related to differences in diabatic processes with height?

20) p16l7: “. . . begins dropping earlier, . . .”: earlier than when? Please clarify.

21) p16l7: “. . . period between the beginning of the MFW and the split . . .”: is it the period between the two dashed lines? Please clarify.

22) p16l19-21: “In fact, as seen in Figure 13, a coherent mass of air from the blue vortex persisted into April – represented in Figure 15 by the individual purple points labeled “transient”,. . .”. I guess these transient vortices are those seen in the supplementary animation and labelled 4, 5, 6, 7 and 8 at the 490 K. If yes, please mention it.

23) p18l8: “. . . one previous winter.”. Please recall which winter it is.

24) P20l1-2: “This is particularly interesting given reported differences between years with early and late Arctic final warmings, which have not, in general, accounted for the suddenness of those final warmings (e.g. Waugh and Rong, 2002; Akiyoshi and Zhou, 2007);. . .”. In recent studies on Frozen-In Anticyclones (FrIACs), tracer transport was linked to the suddenness/abruptness of final warmings (see e.g. Allen et al. (2012), Thiéblemont et al. (2013) or Thiéblemont et al. (2016)).

References:

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