

REPLIES TO REFEREE #3 COMMENTS

The paper is well-written with a lot of references showing the scientific interest of this topic.

Thank you for this review.

General comments: It is not sufficiently shown in the paper if the authors focus on 2009/2010 winter or if they want to characterize all the previous winter since 2003/2004. They show a lot of very sensitive dynamical parameters but do not use them with sufficient details. They describe some local characteristics of the plots and conclude. Because there is a lot of information not used in the graphs presented, it is not easy to be convinced about their concluding remarks. Perhaps adding several tables with the characteristics highlighted of the winters considered could give more clarity.

We have revised the manuscript in accordance with these suggestions. Please find the details of the revision below.

There is no real link between the dynamical discussion in part 3,4 and 5 that allows them to define the proxy (mean zonal wind in January) they use in the last part to conclude on the ozone loss observed each winter since 1985. This last part appears to be another discussion. In its present form, paper objectives are not clearly defined. What's the link between the part on ozone loss and the dynamical study developed before, no link is provided by the authors between both.

We wanted to show how the warmings affect ozone in the polar winter stratosphere. To do this, we discussed various features of the warmings of the winters in [Section 3/4](#) and then, associated changes in ozone abundances in [Section 5](#). Therefore, to put that into perspective we used 17 years of data instead of 7 years, which are too short to demonstrate our goal. We have specified this in the text in detail. Please find the revised [Section 5, Paragraphs 1, 4, and 5](#) and [Section 6.2, Paragraph 1](#)

Title The title is perhaps not well chosen. The authors characterize all 7 winters in the same way from 2003/2004 and do not focus their paper on the 2009/2010.

In order to compare one winter with the other, we had to perform the same kind of analysis for all winters. Therefore, the analyses are same for all winters, although the winter 2009/2010 is focused here. However, we have slightly changed the title to "A major sudden stratospheric warming in the Arctic winter 2009/2010: comparison to other Arctic winters" to be more specific about the major warming of the winter 2009/2010 and comparison to other Arctic winters. Please find the new title.

Abstract p. 7244 L6 : Suggestion in red : "An . . . (SSW) by the reversal of winter westerlies in . . ." L9-11 : "The associated vortex split confined to altitudes below 10 hPa and hence, the major warming (MW) was a vortex displacement event" Comment : This is confusing since split and displacement events are different. I think this is more an altitude dependence : split below and displacement above but this must be better clarify.

Yes, the definition depends on the altitude 10hPa and the central date of major warming (MW). We have discussed this in detail in [Section 3.3, Paragraph 3](#) and [Section 6.1, Paragraph 3](#). Since there are limitations to include all these details in [Abstract](#), we have slightly revised these sentences in the [Abstract](#).

General comment: I think it could be a bit confused for the reader between SSW and MW since in the abstract the difference or the link is not explained.

We have used only "MW" in the revised abstract. Please find the revised text in [Abstract](#)

p.7245 L 4 : Reference needed: "In some extreme cases the temperature rise ..."

We have cited Limpasuvan et al. (2004) in Introduction, Paragraph 1, Lines 8—9

L4 : "The accompanied zonal wind reversal displaces or splits the polar vortex toward mid-latitudes" Do you speak about the study of Charlton and Polvani (2007) ?

Yes. This has been cited in Introduction, Paragraph 1, Lines 10—11

L13 : Comment: The authors have to define Major Warming before discuss about them, please invert the third part and the second part. L 21 : Comment: in the fourth part, the definition you use for your study to define MW has to be given in the part data and method. Comment: Reorganise the introduction defining first MW, SSW and the link between MW, SSW, Minor Warming.

We have reorganised these paragraphs. Now the definitions come in Introduction, Paragraph 2, where the link between MW, SSW and minor warming is also given. However, we have given the definition that we used in this study in this paragraph itself, to avoid repetitions in Section 2. We hope that the referee will find it as an appropriate decision. Thank you.

p.7246 L 2,3,28 : add to N when you refere to latitude 60°. Comment : Reference: In this introduction use the results of (Ayarzagüena, 2011) since it's also a 2009/2010 MW study and the paper of Orsolini et al., 2010 (JGR) since it's a last decade SSW study.

We have added "N" in Introduction, Paragraph 3, Lines 8—12. These publications are cited in Introduction, Paragraph 5, Lines 20—23

2. Data analyzes and methods

Equation (1): please denotes temperature by T and, in equation (3) and (4) this symbol is used for "any function of entropy" after.

Done. Please find the revised Equations in Pages 2—3

3 Synoptic evolution of winters; 3.1 temperature and zonal wind

Comments: The figures 1 are not used in detail. There are a lot of differences in the evolution of temperature and zonal wind each winter but you do not describe them. For example : for the 2007/2008 it is never said that the temperature evolution at 90° N presents several important peaks (Jan-Feb) whereas other winters present just one major peak. Do you want to conclude in this part that all winters are very different regarding those parameters, or to find some general characteristics?

Figure 1 was introduced to check the MW criteria and central dates only, as noted in the text. Because a detailed discussion on the temperature structure of each winter was presented with respect to Figure 2 in Section 3.1.2. Therefore, other features of the temperature curves were not discussed in Section 3.1.1. However, we have included additional discussions on these in the revised manuscript in Section 3.1.1, Paragraph 1, Lines 11—20

Suggestion : Because 2004/2005 and 2006/2007 winters are really different comparing to other ones and because you do not consider them after, it could be better to help the reader plotting specific figures for these two winters, and as a consequence the figures will be more clear and analyses of the five others winters more easy.

We were focusing the winters with MW only, as mentioned in the title and manuscript. However, we have included these winters (2004/2005 and 2006/2007) in the revised discussion. Please find the revised Figure 2 and the revised text in Section 3.1.2, Paragraph 2, Lines 13—24

Figure 1 : The line for 2004/2005 is too thick.

Redrawn. Please find the revised Figure 1

3.1.1 The warming criterion at 10 hPa

Comment: The prolonged 2005/2006 warming seems very closed to the 2003/2004 one at 60° N and 90° N. It seems that the 2005/2006 warming “really” starts around the day -8 until the day +45 while the 2003/2004 starts the day -26 until the day +24.

Noted in the revised text in Section 3.1.1, Paragraph 1, Lines 14—17

3.1.2 Vertical development of the MWs

Figure 2: Are the magenta contours necessary? Comment : in the text and on the figure use a notation “2003/2004” and not just 2004 in order to be in agreement with your previous and following figures. p. 7251 L 20, Comment: “In 2003/2004, relatively lower [. . .] in any other Arctic winters”. I don't understand this statement/conclusion and I don't see the feature by comparison with the other winters.

We have removed the magenta contours and given titles like “2003/2004”. Please find the revised Figure 2 and the revised text in Section 3.1.2, Paragraph 2, Lines 13—28

3.2 Fluxes and waves

p. 7252 L 5 :The heat flux you report in the text for 2009/2010 during MW is really lower than in your figure.

The heat flux is around 200 m Ks⁻¹ and is corrected in the text in Section 3.2, Paragraph 2, Line 1

Comment: There is a lot of information in these figures. You do not describe them and compare them in detail. As in figure 1 you use just some characteristics, and do not explore all information you have. What is the conclusion of this part and the link with the next one?

We have explained the main features of the wave activity in 2009/10 and compared to those of other winters. Please find it in Section 3.2, paragraphs 2, 3, and 4.

Section 3.2 deals with the wave activity during the winters, to assist the interpretation of temporal and vertical evolution of polar vortex in each winter and are presented in Section 3.3 (e.g. Labitzke, K. and Kunze, 2009; Manney et al., 2009). Because the analyses of temporal and vertical features of polar vortex are necessary to characterize a warm winter (e.g. vortex split or displacement during wave activity, Why the vortex was split ? or Why the vortex was displaced to midlatitudes?, etc.). Please find the revised text in Section 3.2, Paragraph 1, Lines 3—12

General Comment on part 3.1 and 3.2 : Perhaps a table could summarize your analysis and the different characteristics you have found to better compare the 2009/10 winters to other ones. In this table you could perhaps do the link with the part PV diagnostic by highlighting the characteristic you want to illustrate with PV maps.

Thank you for this suggestion. We have included a table with prominent features of the MW in each winter. Please find Table 1 and the revised text in Section 3.3, Paragraphs 1, 3, 4, and 5

3.3 PV diagnostic

p. 7253 L 21 : you have not a 3.3.2 part, the subtitle 3.3.1 is not justified.

We have removed the subheading

p. 7254, L 19 : the date 5 January 2003/04 does not appear on maps.

L13-L26 : In the first part of the second paragraph, you do not refer in the text to 850 K or 475 K panels, this is a bit disturbing to follow the text with figures. More details would be expected on this last part which could be considerably improved.

-Comment : The dates you have chosen for PV maps are not sufficiently justified (p.7253 L 16-18), you must use the previous figures to define the conditions of selected dates and why you have selected them. You have to find one or several parameters for justifying your choice. Otherwise your conclusions are not justified, because we do not know what you are comparing and what you want to show.

We have completely revised Section 3.3 with revised figures having common dates for the PV maps. Please find the new Figure 4 and Figure 5, and the revised text in Section 3.3, Paragraphs 1, 3, 4, and 5

Perhaps zonal PV mean time evolution could help you to justify your choice?

-Comment : The conclusion of this part is that all winters are very different?

We thought to present the effect of MW on the temporal and vertical evolution of polar vortex in each winter. Therefore, the zonal mean PV data are not useful here. Yes, If we compare the evolution of dynamical activity in each winter, the winters are different, as explained in Sections 3, 4, and 5

Figures 4 and 5 : Please mention at the top of the plate for each column the winter considered with the notation "2003/2004".

Done. Please find the revised Figure 4 and Figure 5

5. SSW and ozone loss

Please conclude previous each part and use the concluding remarks for justifying your new proxy otherwise it is just a hazard to discover this potential proxy. With this proxy it means that at the end of January you can predict the ozone loss, and this every year?

Please find the reply to comment #1 of REFEREE#1. Thank you. We have removed the proxy term now and the discussion has been revised. Please find the revised text in Abstract and Section 5, Paragraph 5

6. Discussion and conclusion

A lot of new studies are cited for the first time and too much new information is given. The discussion is not clear, and not well structured. This part must be improved by including subsection 6.1, 6.2. . . with a relevant title.

We have split the section (to 6.1 and 6.2 now). This is a very good suggestion. Thank you. Please find the revised discussions in Section 6.1, Paragraphs 3 and 4 and Section 6.2, Paragraphs 2, 3, and 4

p. 7260 L 3-7 : the sentence "each winter is different with respect to the chemical and dynamical processes associated with them." is not well adapted and ask more questions than answers on the study you present.

We have removed the sentence and the discussion has been revised in Section 6.1, Paragraphs 1, 2, and 3

p. 7258 L25 : typo error 2008/09 and not 208/09

Corrected in Section 6.1, Paragraph 3, Line 1

We thank REFEREE#3 for his/her detailed and critical review of this manuscript. We appreciate the time he/she spent for this review.