REPLIES TO REFEREE #1 COMMENTS

General Comments: The authors provide a convincing examination of the evolution of the sudden stratospheric warming (SSW) of 2009/2010 in comparison to other major warming (MW) events of the 2000s decade. As far as I understand the aim of the paper is to provide a comparative study of the MWs of the 2000s decade and to contribute to the understanding of the origin and evolution of the MWs, which is still a challenging effort because – as the authors show – each of the MWs was unique. From my point of view the paper gives new and important aspects for understanding the MWs during arctic winter of the 2000s decade and associated variability in stratospheric ozone. Overall the paper is well-written and worthwhile to be published in ACP. However, I have some few specific questions, and I recommend some few minor improvements before final publication.

 # We thank referee#1 for his/her critical review and recommendation for publication.

Specific comments:

1) p. 7244, ll. 22-23, p. 7257, ll. 21-22, p. 7259, l. 21, and Figure 7: It is evident that a SSW, which is a phenomenon of stratospheric dynamics, has a strong impact on the ozone distribution by changing the tracer transport and temperature-dependent chemistry, therefore stratospheric ozone is a good indicator for what is going on during a SSW, and there might be also feedbacks of the changing ozone distribution on the occurrence rate of SSWs via radiative forcing; however, suggesting ozone loss "as a proxy for MWs" is not really a good idea because there are year-to-year changes in PSC-related ozone chemistry driven by anthropogenic emissions in addition to the effects of dynamics, which complicates an unequivocal definition of minor and major SSWs in terms of ozone distribution or ozone loss.

 # The proxy term was used for the zonal wind, NOT for ozone or ozone loss. We admit that this was not clear in the text. We have removed the proxy term and discussed various aspects of the correlations in the revised manuscript. Please find it in Abstract and Section 5, ParagraphS 3, 4, and 5

From my point of view it would be more interesting to discuss whether the strong increase of the occurrence rate of MWs during the 2000s decade could have masked the PSC-related ozone loss due to anthropogenic emissions, i.e. whether the widely discussed ozone recovery since the mid-1990s could be primarily due to the increase in MWs and not to the restrictions in anthropogenic emissions of CFCs and some halons. Could you make a comment on this possibility?

 # Good point. Thank you for this. We have presented a detailed discussion on this in the revised manuscript. Please find the revised text in Section 6.2, Paragraph 3

2) p. 7250, ll. 6-8: Do you have an explanation for this "striking feature"? Usually the centre of the polar vortex does not coincidence with the geographic North Pole, but sometimes it does. Is the different behaviour of the temperature at 60◦N and the 90◦N during 2007/08 just related to the location of the polar vortex, i.e. to a weaker zonally asymmetric structure of the vortex than during other years?

 # The easterly jet was stronger at higher latitudes and the polar vortex was shifted off the pole at most times during this period. This has been mentioned in Section 3.1.1, Paragraph 2, Lines 8—11

3) p. 7254, ll. 8-9: In Figure 5 (475K, 100128) the vortex is not really near the pole but the centre of the vortex is located over northern Siberia; over this region the vortex is found most frequently.

 # Corrected. Please find it in Section 3.3, Paragraph 2, Lines 19—20

4) p. 7255, ll. 25-26: What do you mean exactly with "an advanced shift of 5-7 days"? It would be helpful to be somewhat more precisely at this point, because it is difficult to realize this feature based on the figures alone. For example, for the red line (2009/2010) I can identify 3 pronounced peaks in wave 1 EPz flux between mid December and mid-January, and 3 pronounced peaks in wave 1 with a

time lag of some days (similar for wave 2 between around 20 December and end of January). Do you mean here this kind of relationship?

 # Yes. These sorts of pre-warming anomalies in heat flux/EP flux have been shown before [e.g. Newman et al., 2001 and Polvani and Waugh, 2003]. These have been mentioned in Section 4, Paragraph 2, Lines 22—26

5) p. 7256, ll. 4-6: It would be helpful to give some more few comments on these findings of the wave activity in the troposphere, because it could help to understand the processes initiating the SSW. For example, is it possible to formulate a link between the features shown in Figure 6 and the mentioned findings for tropospheric wave activity?

 # Yes. We have added an additional paragraph to explain the tropospheric influence on the SSWs. Please find the revised text in Section 4, Paragraph 3

Technical corrections / Typing errors:

1) p. 7245, l. 1: As far as I know the term "vacillation" is usually used for short-term fluctuations, for example the regular vacillations during a winter period shown in Figure 1, 3 or 6. Therefore here the term "year-to-year variability" seems to be more appropriate.

 # It is interannul variability. Corrected in Introduction, Paragraph 1, Line 4

2) p. 7245, ll. 15-16: It is not specified what you mean with "... induce heat ..."? For example, do you mean here adiabatic heating via changes in the Brewer-Dobson circulation, or heating of the cold polar vortex due to eddy mixing processes?

 # During a warming, deceleration of the westerlies leads to downwelling and adiabatic heating of stratospheric air. This has been mentioned in the revised text in Introduction, Paragraph 4, Lines 15—16

3) p. 7252, l. 9: What do you mean with the term "mountainous upward EP flux"?

 # Large heat flux. Changed in Section 3.2, Paragraph 2, Line 7

4) p. 7252, l. 11: Obviously it should be "geopotential wave 2 amplitude" and not "geopotential flux".

 # No, this was geopotential flux and was not shown in the figure. Therefore, we have removed this in the revised text.

5) p. 7258, l. 25: It is "2008/09" and not "208/09".

 # Yes. Corrected in Section 6.1, Paragraph 3, Line 1

6) Figure 3, figure caption: It is not specified that the dark contours denote the zonal mean westerlies.

 # Done. Please find the revised Figure 2 (not Figure 3) caption.

7) Figure 6: It would be nice if the axes of total, wave 1 and wave 2 EPz fluxes are the same (e.g., -1 to 5); also for wave 1 and wave 2 (e.g., -10 to 40).

 # Corrected. Please find the revised Figure 6

8) Figure 7: The ozone column loss is only given in relative units, but the reference state is not specified (presumably a long-term mean of ozone column).

 # A passive tracer initialised together with ozone at the beginning of each simulation/winter is the reference for the ozone loss estimation here. The ozone loss (in relative units) is computed as: [100* (passive tracer - ozone)/passive tracer]. The vortex edge is taken as 35 pvu and the vortex edge criterion is considered at 475K. The passive tracer simulations are performed with the REPROBUS chemistry transport model. Please find the revised text in Section 5, Paragraph 2, Lines 7—16

We thank Referee#1 for his/her quick and thorough review of this manuscript and for the time he/she spent for this review.