Interactive comment on "Observations of PW activity in the MLT during SSW events using a chain of SuperDARN radars and SD-WACCM" by N. H. Stray et al.

Anonymous Referee #1

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General Comments

In this study by stray et al., the authors study the MLT planetary wave activity following SSW events from a network of SuperDARN radar measurements and simulations from specified dynamics WACCM. The authors show compelling evidence of enhanced PW activity (s1 and S2) in the MLT with a 3-day lag from stratospheric wind reversals at 50 km. The enhancement in PW activity is seen not only after strong SSW events with elevated stratopause events but also after smaller magnitude SSW events where the wind reversals might persist for only up to 4 days. The authors speculate that the enhancement in PW activity might be due to in-situ generation of PW in the MLT by either zonal asymmetry in GW drag or due to the development of baroclinic/barotropic instabilities.

Specific comments

1. Line 31-33 (ACPD page 395 line 11ff).This sentence is factually incorrect. There is no evidence that PW in the MLT initiate the descent of the elevated stratopause events. In fact the studies cited by the authors seem to indicate that the formation and descent of the elevated stratopause is gravity wave driven while the westward PW activity might be having some contribution.

   The reviewer is right that both GW and PW can contribute to the formation and decent of the elevated stratopause. The sentence has been changed to:

   The sentence on page 395 line 11ff has been changed to
   Along with westward gravity wave drag, momentum deposition by PWs also contributes to the formation and descent of the elevated stratopause (Limpasuvan et al., 2012).

2. Line 52 (ACPD page 396, line 5). How do you define 'strong' events? It might be prudent to mention the WMO definition of major and minor SSW events. The strong event of 2012 studied in Chandran et al. 2013b is actually a minor SSW event.

   The strong event of 2012 studied in Chandran et al. (2013b) persists for approximately 7 days, reaches maximum westward wind speeds above -35 m/s during the reversal and is followed by an ESE. This event is a good example of a strong event that only shows up as a minor SSW in the traditional WMO definition.

   The following sentence has been included in paper (page 398, line 11) to clarify the definition of strong events:
   SSW events have been defined as strong events when their zonal-mean zonal wind reversal in the stratospheric (50 km) polar cap wind (70-90 N) persists for 4 or more days and exceeds westward wind magnitude of 10 m s^{-1}.

3. Since the SuperDARN radars cover only 175^{o} in longitudes it is not clear how this would affect the determination of especially wave 1 components keeping in mind that often

during SSW events of a vortex displacement nature, the winds in one hemisphere might not even show a reversal. I think this might be biasing the amplitudes of the wave 1 components shown in the study. A more detailed discussion is warranted here.

The analysis has been validated and quantified in Kleinknecht et.al (2014). In this paper we showed that the amplitude and phase of the S_1 wave retrieved using the analysis was well correlated (correlation coefficient=0.9) with an ideal 360° longitude fit (2.5° spacing).
It was also shown that the amplitude of the S_1 and S_2 wave components agreed with the ideal fit to within the fitting uncertainties (± 20% and ± 10%, respectively). Consequently, we are confident that biases in the derived amplitudes are minimal.

The paper has been changed to include the *following statement* in line 25 on page 396:

… The resulting daily winds are fitted as a function of longitude to provide the amplitude and phase of the S_1 and S_2 PWs. *Kleinknecht et.al (2014) verified the amplitude and phase of the retrieved wavenumber components to correlate well (correlation coefficient: 0.9) with an ideal fit covering 360° of longitude (2.5° longitude spacing). The amplitude of the S_1 and S_2 wave components agreed with the ideal fit to within the fitting uncertainties (± 20% and ± 10%, respectively).* The wave number one (S_1) and two (S_2) components resulting from the fit to the chain of SuperDARN radars are shown in Fig. 1 …

4. SD- WACCM model output- What are the time steps in the model outputs used in this study? How does it affect determination of the S1 and S2 wave components?

   SD-WACCM output is written instantaneously once a day. Given this temporal resolution, the determination of S_1 and S_2 signals would discount the influence from tidal effects. As noted in Smith (2012), non-migrating tidal amplitudes around the MLT tend to be very small poleward of 30°N. Zonal wavenumber 1 migrating tidal meridional wind amplitude (i.e., DW1) can reach 6-8 m s^{-1} in higher latitudes, but they tend to occur just after the equinox. Zonal wavenumber 2 migrating tidal meridional wind amplitude (i.e., SW2) tends to weaken significantly in the high winter latitude. To this end, we believe that tidal influence should not contribute significantly in the mid- to high- latitude compared to S_1 and S_2 planetary wave extracted from the SD-WACCM output.

5. Line 95- 110. (ACPD, page 398 line 8). The authors should mention that their definition of an SSW event differs from the traditional WMO definition of SSW events. While I do not have any issue with the authors definition of strong SSW events, to make a comparison with other studies which have followed the WMO definition it might be worthwhile to mention which of the seven events composited meet the WMO definition of a major SSW and which ones do not. Looking at table 1 in Chandran et al. 2014, I see only two events classified as SSW with ES events during the study period and 7 events classified as major SSWs during this period. A table might be in order here listing the authors classification of ‘strong’ and ‘weak’ SSW events and SSWs with ES.

   Only two of the studied 7 events develop into major SSW events according to the WMO definition.

   Since the timing between the polar cap wind at 50 km and the wind at 30 km and 60°N (the WMO definition) varies for each of the events, we feel a table might be confusing.

The WMO defined these criteria due to their correspondence with stratospheric warming effects. However, Tweedy et al. (2013) found the behavior of the polar cap wind at 50 km is better associated with the mesospheric effects studied here. Thus, the text of the paper has been changed to clarify that the definition chosen here is different from the WMO definition, and why this alternative definition has been used.

The text on page 398 line 8 has been changed to read: *The reversal of the polar cap wind at 50 km was used to identify the events following Tweedy et al, (2013), who found that this criterion was a better indicator of the wind reversal extending into the mesosphere and the onset of vertical upwelling than the WMO (World Meteorological Organization) definition of SSWs* at 10 hPa and 60° latitude*. Using the polar cap wind reversal at 50 km, only two of the events classified as strong would be considered to be major stratospheric warmings according to the WMO definition. SSW events have been defined as strong events when their wind reversal in the stratospheric (50 km) polar cap wind (70-90 N) persists for 4 or more days and exceeds westward wind magnitudes of 10 m* s^{-1}*..*

6. Line 115. (ACPD, Page 399 line 5) Figure 2. Looking at figure 2, I see that the zonal mean winds do not show a reversal at 10 hPa for the composite of the 7 strong events. Again this is following on from the previous comments that the reader might not have the same definition of the authors on what constitutes a strong SSW event. Also the composite of the SSW ES events do now show the traditional image of an ES structure where we expect the ES to form around 80 km similar to the temperature structures seen in events such as 2006, 2009 SSW events or the composite of ES events shown in figure 5 of Chandran et al. 2013a. I suspect this is because of the author's choice of altitude difference to be 10 km. I am curious if the results show any difference if the authors select a subset of SSW events with an altitude difference of say 15 km instead.

   The zonal wind in the composite does not show a reversal at 10 hPa since most of the events are not related to major stratospheric warmings as defined by the WMO (see response to comment 5). In addition, the time lag between a reversal at 50 km, our zero-index point for the composite, and a potential reversal at 10 hPa varies from event to event. This variation would serve to further blur any such reversal at 10 hPa in the composite.

   Similarly, the composite does not show a clear reformation of the stratopause at 80 km. This is mainly due to:

   1) Stratopause jumps between 20 km and 42 km are included in the composite of 7 events, "blurring" the altitude width of the jumps.

   2) The composite is set to the onset of the wind reversal at 50 km and not to the occurrence day of the stratopause jump. Since the length of the wind reversals of the 7 events are different, the stratopause jump occurs at a different times relative to the zero-index point for the composite, This, as with the wind reversal at 10 hPa mentioned above, leads to a blurring of the elevated stratopause effect in the composite. However the elevation of the stratosphere is clearly visible at around 70 km after the event. (While a composite could be constructed to show the elevated

stratopause more clearly, the focus of the paper is on the planetary wave enhancement following the wind reversal at 50 km, and the composite is constructed accordingly).

The following sentence has been added on page 400 line 5: *Although each of the 7 events shows a stratopause jump between 20 and 42 km, the composite shown in Figure 2 is indexed to zero on the day of the wind reversal at 50 km (defined to be the onset date) and not at the occurrence of the ES event. Therefore the mean elevated stratopause, although clearly visible at around 70 km after the warming, is not representative of the individual stratopause jumps in the composite.*

7. Line 125 (ACPD, Page 399, line 15). 'A SSW' or 'an SSW'? later on the author's use 'an SSW'. Please be consistent.
   Change to "an SSW"
   Page 395, line 6
   Page 399, line 15
   Page 400, line 19

8. Line 135-140 (ACPD, Page 399, line 27ff). This is not very evident in the composite. Again I believe this might be because of the 10 km difference between altitudes selected by the authors to define an ES event.

   The elevated stratopause of the composite reforms at ca. 70 km and is consistent with the definition of an ES event set in this paper. The addition to the text after line 140 to clarify this is detailed in the response to comment 6, above.

9. Line 150 (Page 400, line 16f). How many events out of the seven show the phase speed to be stronger westward and how many show weaker and eastward?

   Three events show the phase speed to be stronger westward and one event shows eastward phase speed after the reversal. For the other three events the phase speed is not significant different before and after the reversal.

   Line 16f on page 400 has been changed to:
   Three events show the phase speed to be stronger westward and one event shows eastward phase speed after the reversal. For the other three events the phase speed is not significantly different before and after the reversal.

10. Line 172 (ACPD page 401 line 15) - When you mention that the amplitudes of S1 and S2 are similar, some important information is missing here. The authors need to mention out of the seven events, how many were vortex displacement and how many were vortex splitting events? If there were instances of both then I believe the analysis for figures 3 and 4 should also include separate panels for VD and VS events. I fear a strong vortex splitting event where the S2 component might be very strong biasing the composite result or vice versa.

Although not selected for this reason, all the 7 events used in the composite show a vortex displacement.

The following sentence has been added on page 401, line 2:

It should be noted that all the 7 events used for the composite happen to be associated with a vortex displacement.

References used:

Chandran, A.; Garcia, R. R.; Collins, R. L. & Chang, L. C. (2013) Secondary waves in the middle and upper atmosphere following the stratospheric sudden warming event of January 2012
GRL, 40, 1-7

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Limpasuvan, V., Richter, J. H., Orsolini, Y. J., Stordal, F., and Kvissel, O.-K. (2012): The roles of planetary and gravity waves during a major stratospheric sudden warming as characterized in WACCM, J. Atmos. Solar-Terr. Phys., 78–79, 84–98, 2012.

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