Reviewer #2:

First of all, the authors would like to thank the reviewer for a very detailed, constructive and critical reviews. Based on the comments and suggestions the manuscript is now much improved. In the following point-by-point responses, the reviewer comments are in italics, typed in brown color and are numbered for further reference.

Specific comments:

1) The authors accounted for dependence of EEJ strength on solar flux values by normalizing to a fixed solar flux of F10.7 = 150. I wonder why this level is so high, as three out of 4 SSW cases used in the study occurred during much lower solar activity. Is there a good evidence that 'corrected' EEJ strength does not depend on the value of solar flux used for normalization?

Response: The 2006 and 2009 SSW events were recorded under low solar flux conditions while the 2003 and 2013 SSWs were recorded under moderate and high solar flux conditions, respectively. In an earlier study, Siddiqui et al. (2015) estimated the lunar tidal power of the EEJ between the years 1997 and 2011 (see Figure 1). They used the solar flux value of 150 s.f.u for normalization and found that the EEJ lunar tidal power showed no solar flux dependence. The lunar tidal power was normalized so that it can be compared across different winter periods.

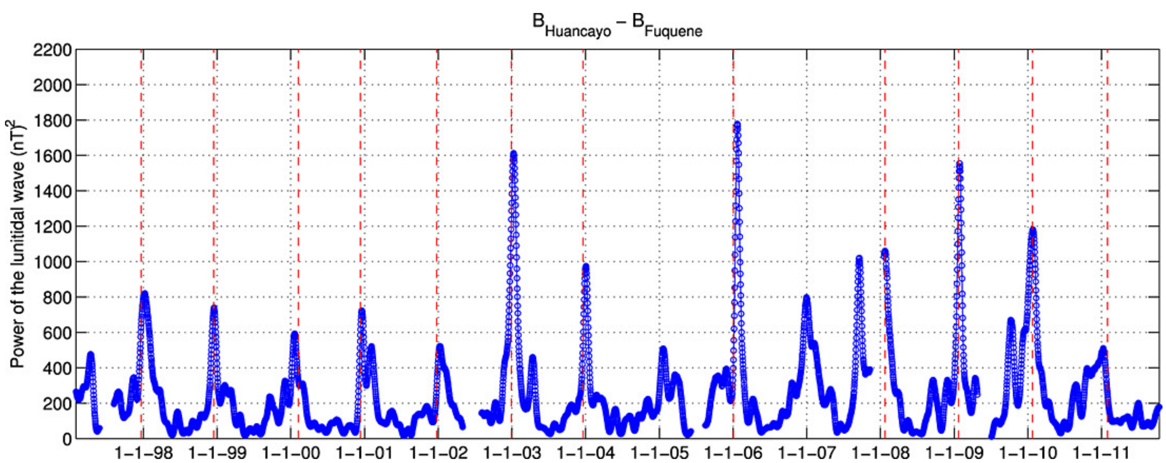

Figure 1: The EEJ lunar tidal wave power for the years 1997–2011 is presented. The red lines denote the days of polar vortex weakening. Figure is taken from Siddiqui et al. (2015).

An important point to note is that other values of solar flux can also be chosen for normalization in order to correct the EEJ strength. However, in this study we have followed the normalization method described in Siddiqui et al. (2015).

2) p. 5, 'We assume constant amplitude and phase of the tidal components within the 21-day window' – as amplitudes change on a shorter time scale, it is important to discuss the influence of this assumption on final results. Also, is there a justification for using a 21-day window instead of 15-day window?

Response: In order to determine the amplitude and phase of the tidal components, we have

used a 21-day window to perform the least-squares fitting in this study. While fitting the tidal components, we derive constant values of the amplitudes and phases of the different tidal components within one such window. This is what we intended to mean by the above statement.
The obtained tidal amplitudes and phases are then assigned to the central day of the window and then the same process is repeated by shifting the window by one day. With the shifting of the window, the tidal amplitudes and phases change depending on the variability of the tidal components. By this approach, we are calculating the tidal variability of the equatorial electrojet in this study. This sentence has been rephrased in page 5, lines 25-28 in the tracked changes file.

Chau et al. (2015) found that when synthetic radar data were used to estimate the solar and lunar semidiurnal tides using least-squares method with a 15-day moving window then the results yielded some artifacts. They found that a 21-day moving window was a good compromise as it allowed the reduction of the artifacts and also the separation of the solar and lunar semidiurnal tides. In order to determine the amplitude and phase of the solar and lunar tidal components, we have therefore used a 21-day moving window to perform the least-squares fitting in this study. This point has been added in the tracked changes file on page 5 lines 21-25.

3) It is not clear from the description if the authors used simultaneous fit to S and L components.

Response: The S and L components have been fitted simultaneously in this study and to clarify this point this sentence has been modified in page 5, line 11 in the tracked changes file.

4) I am concerned about panels with stratospheric data in figures 2-5. The temperature at 10 hPa seems to be very different from figures in previously published papers. For example, in case of SSW 2009, that was extensively studied by different authors, there is a dramatic variation in temperature from below ~200K in December to ~265K during the peak of SSW in the NCEP data, and the temperature is below multi-year average from mid-February to the end of April (see figure). Please check your NCEP data and plotting routine. I have loaded attached figure from https://acd-ext.gsfc.nasa.gov/Data_services/ met/ann_data.html

Response: The reviewer has correctly pointed out the error in the North Pole temperature displayed in the plots. This mistake has been corrected in the updated plots.

5) P. 9, 'To a certain degree, there is a similarity in timing between the enhancements of the SW2 and the S2 over Huancayo' – I am not sure about this, they seem to be pretty different to me.

Response: We have now made extensive changes in the manuscript by including the semidiurnal tides in zonal wind at ~120 km during the 2003, 2009 and 2013 SSWs. This sentence was removed in the new version of the manuscript and the discussion has been revised and extended in pages 9-14.

6) Observations and simulations are given using different temporal scales – why? It makes it more difficult to compare. Was model output available only after Jan 1 and only for 50 days? If model output is limited to a shorter period, how does the use of 21-day window affect tidal results?

Response: The simulation output for the 2013 SSW event is available from 15 December 2012 to 2 March 2013 as the study performed by Maute et al., (2016) focused specifically on the tides during the SSW period. For this work, new simulations for the 2013 SSW event were not performed because we preferred to use the simulation results that have already been published and validated with observational data. As we have used a 21-day window for the calculation of solar and lunar semidiurnal tides, the tidal signals from the model output have been presented up to 50 days after 1 January 2013. The simulation outputs for the 2003 and the 2009 SSW events do exist from December onwards to March but in order to display all the simulation results in a common format we opted to present the plots in this manner.

Figure 2, taken from Maute et al. (2016), shows the M2 and SW2 tides in the zonal wind at ~120 km, which were obtained using a 14.5-day window. In this study, we have used a 21-day window to calculate the M2 and the SW2 tide and the results are presented in Figure 3. We do not see much difference on the tidal results with the change in the window size.

<u>**14.5-day window**</u>

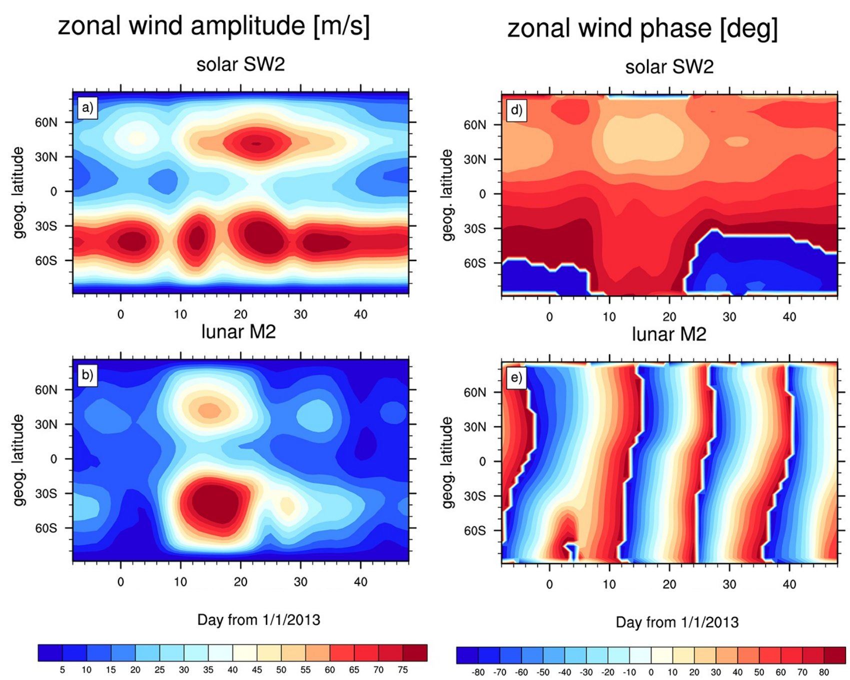

Figure 2: Amplitudes (m/s) of (a) SW2 and (b) M2 at ~120 km in zonal wind using a 14.5-day window. (d–e) Zonal wind phase defined as the longitude (degrees) of maximum at 0 UT for SW2 (Figures 2a) and M2 tide (Figures 2b). Figure is taken from Maute et al. (2016).

21-day window

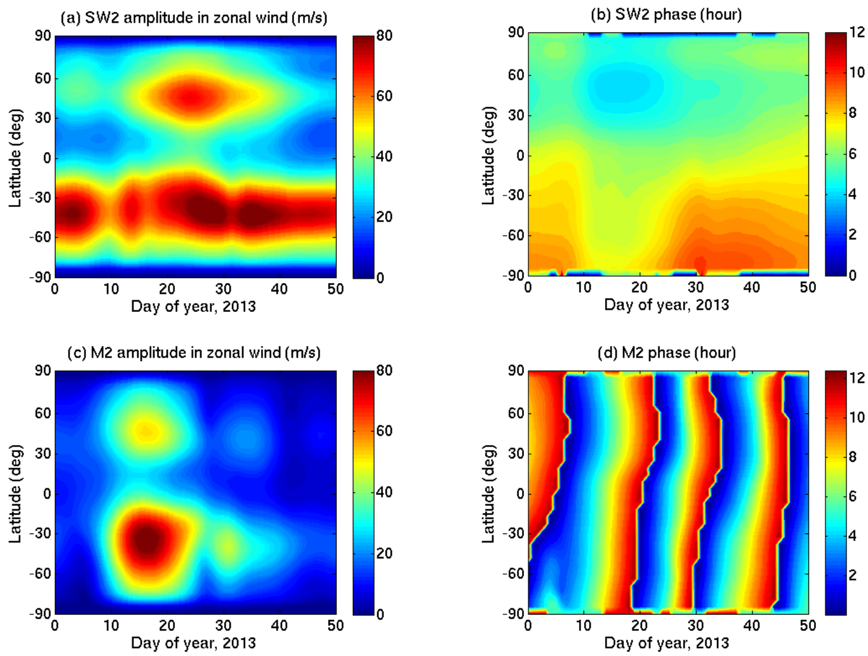

Figure 3: Amplitudes of (a) SW2 and (c) M2 in zonal wind at ~120 km using a 21-day window. The corresponding phase for SW2 and M2 are plotted in (b) and (d), respectively.

7) The presented simulations are difficult to interpret. Besides different temporal periods, the authors use different parameters, EEJ strength in data and temperature in the model. Is it possible to process simulations to calculate EEJ strength from the model output, and compare observed and simulated EEJ? At the very least, it would be useful to add a discussion on how temperature at middle latitude is related to EEJ at the equator. Brief description is given on page 10, lines 23-24 – I suggest to extend it and move earlier, before discussing simulations.

Response: In the revised version of the manuscript, we have included the SW2 and M2 tides from the zonal wind in addition to the semidiurnal tides in neutral temperature. As the variability of the E-region zonal wind is more closely related to the variability of EEJ, we believe that by including these new results our arguments would be better clarified.

Though we do not directly compare the observed and simulated EEJ in the present study, this has been done previously for the 2009 and 2013 SSWs. Pedatella et al. (2018) compared the 2009 simulations used in this study with ExB drifts observed at Jicamarca, Peru (see Figure 4) and with the EEJ strength over the Indian sector (see Figure 5) and found that the models reproduced the observations to a very good extent. Likewise, Maute et al. (2016) also performed a comparison between the simulated ExB drifts during the 2013 SSW and the ExB drifts from the JULIA radar at Jicamarca (see Figure 6). The 2013 SSW simulations were found to reproduce the main features of the SSW related drift variability. These previous comparisons are one of the reasons for using these simulations and as the comparisons with the observed ExB drifts and EEJ strength have already been performed in the aforementioned works it has therefore not been again attempted in this study.

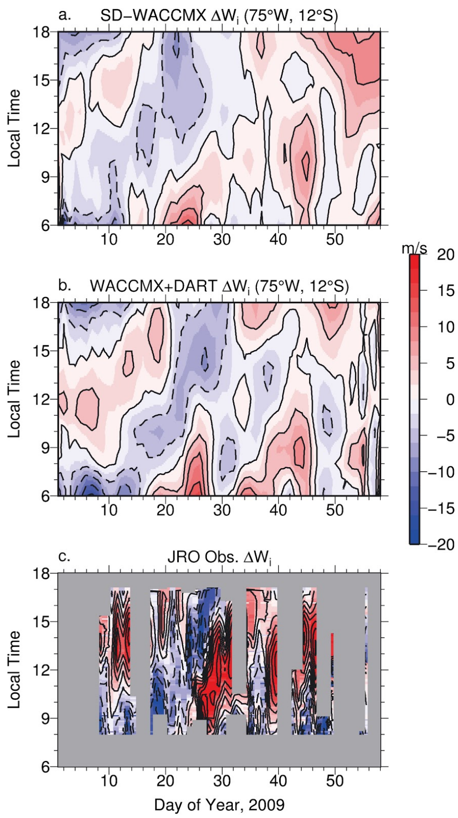

Figure 4: Change in the vertical plasma drift velocity at 75°W longitude and 12°S latitude for (a) SD-WACCMX and (b) WACCMX+DART (c) Change in vertical plasma drift velocity measured by the Jicamarca incoherent scatter radar. Changes are calculated relative to the January–February 2009 mean value at each local time. Figure is taken from Pedatella et al., 2018

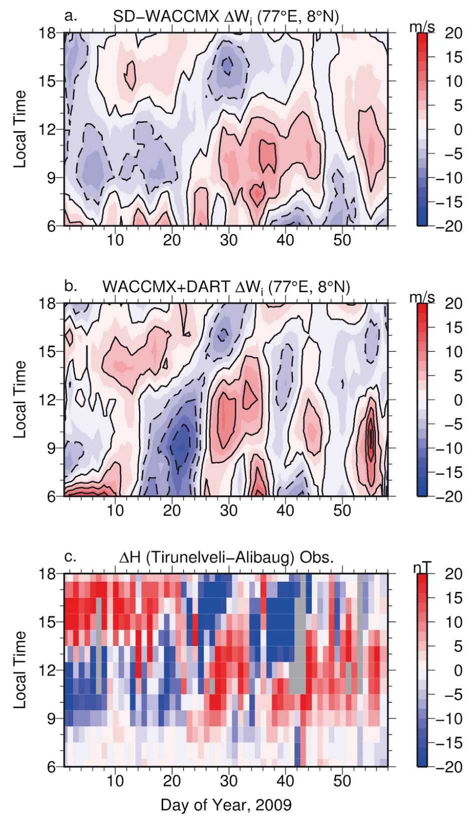

Figure 5: Same as Figure 4 but for 77°E longitude and 8°N latitude. The horizontal component of the geomagnetic field between Tirunelveli and Alibag are used to derive the EEJ strength which has been used for comparison with the model derived plasma drift velocities.

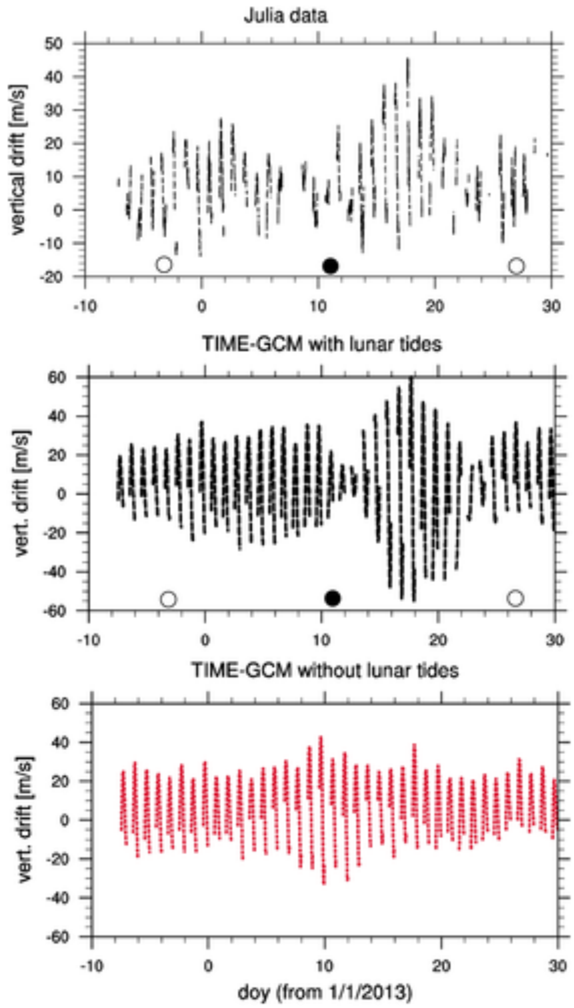

Figure 6: Vertical drift at Jicamarca location between 7 and 18 solar local time over day of the year with 1 January 2013 as day 1: (top) JULIA observations; TIME-GCM E × B drift simulation at ~120 km (middle) with and (bottom) without lunar tidal M2 and N2 forcing at the lower boundary. Full moon and new moon are depicted by the white and black circles, respectively, at the bottom of the panels. Figure is taken from Maute et al., 2016.

We have now revised the discussion after adding the solar and lunar semidiurnal tides from zonal wind at ~120 km in the updated manuscript and hope that the concerns of the reviewer have been addressed.

8) Simulations are presented essentially for three different models, and there are major differences between simulated SW2 and M2 in the magnitude of tidal modes, temporal evolution, and latitudinal structure of tidal modes, especially for the M2 mode. The differences exist between different simulations, but as they are also used for different SSW cases, it makes it difficult to assess what models are getting correctly and what they are not getting correctly. What is the justification for using three different models.

Response: As mentioned in the response to the previous question**,** the simulation results of the 2009 and 2013 SSWs used in this study have already been published by Pedatella et al. (2018) and Maute et al. (2016), respectively. In their works, the simulated ExB drifts have been compared and validated with the observed vertical plasma drifts at Jicamarca, Peru and a good agreement was obtained in both these studies. Therefore, it is reasonable to use the already validated simulations. We also wanted to exploit the existing simulations and gain new insights by comparing simulations from different studies and therefore used them instead of re-simulating the SSW time periods.

One downside of using these simulations is that they have been performed by using different models and there are major differences particularly in the estimated tidal amplitudes. The reviewer has correctly pointed out that it is difficult to perform a one-to-one comparison among the three different model simulations. We agree with the reviewer on this point but the main motivation for including simulation results in our study was to investigate the latitudinal structure of the SW2 and M2 tide during the 2003, 2009 and 2013 SSWs. We wanted to understand the SW2 tidal variability at the E-region altitudes during the SSWs.

The reviewer may refer to the studies by Pedatella et al. (2018) and Maute et al. (2016) for more details on the assessment of model capabilities.

9) As the authors choose to present tides in neutral temperature in simulations, they could compare simulations results with SABER results presented by Zhang and Forbes, 2014 (Zhang, X., and J. M. Forbes (2014), Lunar tide in the thermosphere and weakening of the northern polar vortex, Geophys. Res. Lett., 41, 8201–8207, doi:10.1002/2014GL062103. I am particularly concerned about the latitudinal structure of lunar tide and the timing of the amplifications in lunar tide. There are significant differences between Zhang and Forbes observations and simulations presented in this paper. I am concerned that the authors overstate the levels of success in simulations.

Response: The reviewer has mentioned an important point about the comparison between the neutral temperature in simulations and SABER results presented by Zhang and Forbes, 2014. The comparison of M2 and SW2 from neutral temperature in simulations and SABER temperature data is an important topic that we would like to separately address in the future.

In the following section, however, we compare the latitudinal structure and the timing of amplification of the lunar tide obtained from simulations with those of the lunar tide obtained from SABER temperature data during the 2009 and 2013 SSWs.

There was an error regarding the dates in the M2 plot for the 2009 SSW event in the manuscript, which has been corrected and again verified. For the 2009 SSW event, the M2 tidal amplitude in neutral temperature from WACCMX+DART simulations (Figure 7) do reproduce some of the features of the M2 tide from SABER observations (Figure 8) but there are also some major differences. The M2 enhancements in the simulations are seen a few days earlier as compared to the M2 enhancements in observations. The M2 tidal amplitudes obtained from the SABER temperature data are also much stronger as compared to the one obtained from the WACCMX+DART simulations.

2009 SSW

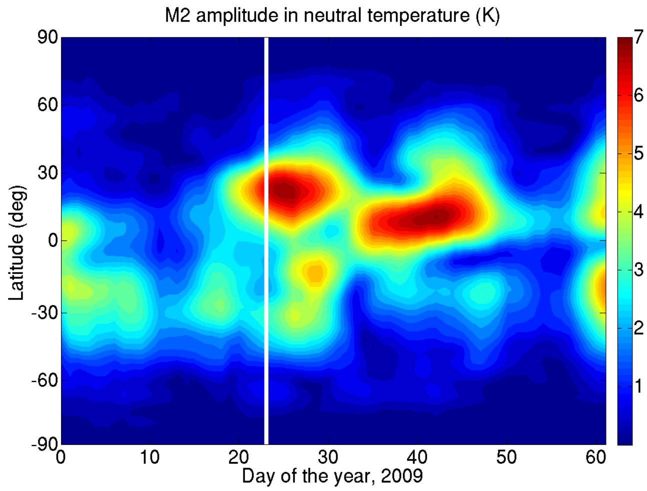

Figure 7: M2 from WACCMX+DART at ~110 km of altitude.

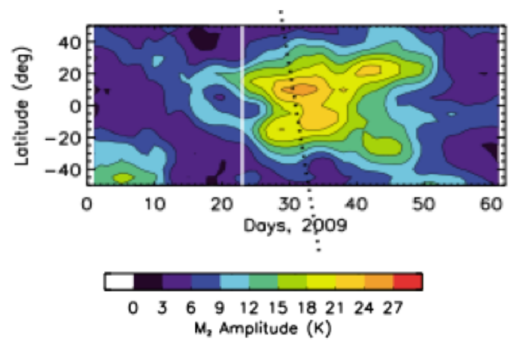

Figure 8: M2 from SABER temperature observations at 110 km. Figure is taken from Zhang and Forbes (2014).

2013 SSW

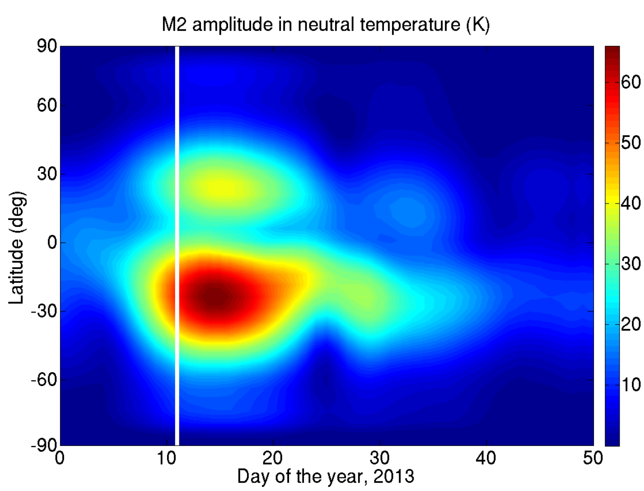

Figure 9: M2 from TIME-GCM at ~110 km of altitude.

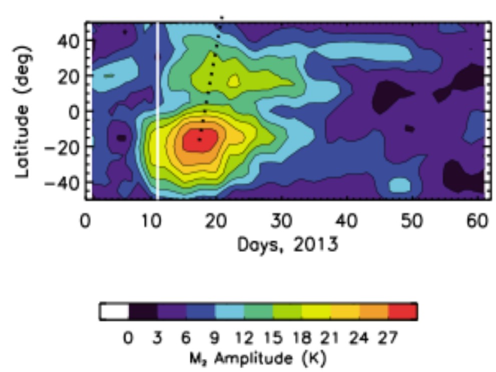

Figure 10: Same as Figure 8 but for the 2013 SSW event.

For the 2013 SSW event, we see a greater similarity in the latitudinal structure of the M2 between the modeling (Figure 9) and observations (Figure 10) results as compared to the 2009 SSW event. The M2 enhancements start to occur relatively at the same time in both the figures and the day of peak amplitudes also seem to coincide. One major difference between these two figures is observed in the amplitude of the M2 tides. The peak M2 amplitudes obtained from the model is more than twice as large as those from the observations. Maute et al. (2016) already pointed out that the lunar tidal component is overestimated in the simulation based on comparison with JULIA drift observations. The cause of the large difference in the M2 amplitude from models needs to be further investigated.

10. Overall, I think the modeling portion of the paper needs more work. It does not provide a solid understanding of the level of agreement or disagreement with observations, and what models can or cannot simulate successfully.

Response: In the updated version of the manuscript, we have also included the plots of the solar and lunar semidiurnal tides estimated from the simulated zonal mean winds at ~120 km of altitude during the 2003, 2009 and 2013 SSWs. More text has been added in discussion to describe and explain these figures. However, we do agree that to make progress in the modeling of SSW and understanding the behavior of models more comparisons between models are needed.

Minor comments:

1) p. 2, 'have reported about the lower thermospheric warming' - have reported the lower thermospheric warming?
Response: The sentence has been corrected.

2) p.2, line 30 – comma after SSW?
Response: The sentence has been rephrased.

3) p. 4, 'which mostly result due to the lunar semidiurnal' – 'which mostly result from the lunar semidiurnal'? Or 'which mostly are due to the lunar semidiurnal'?
Response: The sentence has been rephrased.

4) p.4, 't denotes the solar in hours' – it is not clear; please clarify – do you mean solar time?
Response: The author would like to apologize for the typo. The sentence should have been as follows:
't' denotes the solar local time in hours. This error has been corrected.

References:

Chau, J. L., P. Hoffmann, N. M. Pedatella, V. Matthias, and G. Stober (2015), Upper mesospheric lunar tides over middle and high latitudes during sudden stratospheric warming events. *J. Geophys. Res. Space Physics*, 120, 3084–3096, https://doi.org/10.1002/2015JA020998.

Maute, A., B. G. Fejer, J. M. Forbes, X. Zhang, and V. Yudin (2016), Equatorial vertical drift modulation by the lunar and solar semidiurnal tides during the 2013 sudden stratospheric warming, *J. Geophys. Res. Space Physics*, 121, 1658–1668, https://doi.org/10.1002/2015JA022056.

Pedatella, N. M., Liu, H.-L., Marsh, D. R., Raeder, K., Anderson, J. L., Chau, J. L., et al. (2018). Analysis and hindcast experiments of the 2009 sudden stratospheric warming in WACCMX+DART. *J. Geophys. Res. Space Physics*, 123, 3131–3153. https://doi.org/10.1002/2017JA025107.

Siddiqui, T. A., C. Stolle, H. Lühr, and J. Matzka (2015), On the relationship between weakening of the northern polar vortex and the lunar tidal amplification in the equatorial electrojet, *J. Geophys. Res. Space Physics*, 120, 10006–10019, https://doi.org/10.1002/2015JA021683.