Response to the comments by Anonymous referee #2

Ma et al. (2022) tried to establish a possible new methods of identifying travelling planetary waves in the stratosphere during sudden stratospheric warmings by removing the possible interference of stationary planetary waves. Compared with the traditional method, the authors claim they have several improvements in the identification method. However, a significance test is lack in the paper, and readers might wonder to what extent the results are trustworthy. The difference between the new method and old is also not large, which is also shown for the synthetic (man-made) data from Figures 1-3. Further, this paper focuses more in the mesosphere and upper stratosphere. The largest improvement is very likely not in the lower stratosphere. The results from 100 hPa to 10 hPa should be shown if possible. I did not see any discussion on the origin of the enhanced planetary waves during SSWs. Do they come from the lower atmosphere like troposphere or generate in the middle atmosphere directly? Due to those issues, I would suggest a substantial revision before the paper can be considered.

Response:

We thank the referee for his thoughtful and constructive comments. In the revised manuscript, we replaced the composite analysis with year-to-year results and added some explanations following his suggestions. For those other concerns, we provided a short response here first, and please find our specific explanations in the point-to-point responses.

The difference between the new method and the old was not large, because the amplitudes of the rapid change in stationary planetary waves (SPWs) were not large in the previous simulations. If we set a large amplitude of the rapid change in SPWs, the fake amplitudes obtained from the old method will be more evident. In Figure 3 of the revised manuscript, we changed the amplitudes of the SPWs and provided a more evident difference between the new and old methods.

The largest improvement of the new method is not in the lower stratosphere but in the upper stratosphere and mesosphere, where the traveling planetary waves (TPWs) in the geopotential height measurements have large amplitudes. In general, the rapid and large changes in the amplitude of SPWs are also found in the mesosphere (e.g., Lu et al., 2018), which has a limited influence on the variations of TPWs in the lower stratosphere. Thus, the results from 100 hPa to 10 hPa are not shown due to small amplitudes of TPWs, which are generally below 20 m as a noise level.

The trigger mechanisms of the enhanced planetary waves during SSWs have not been fully understood. Since the basic goal of our manuscript is to propose a new fitting method, we did not discuss the origin of the waves during SSWs. In the revised manuscript, following the referee's comments, we added the discussions on the origin of the enhanced planetary waves during SSWs, please see details in the following responses (specific response to the major comment 4).

Lu, X., Wu, H., Oberheide, J., Liu, H.-L., & McInerney, J. M.: Latitudinal double-peak structure of stationary planetary wave 1 in the austral winter middle atmosphere and its possible generation mechanism. Journal of Geophysical Research: Atmospheres, 123, 11,551–11,568. https://doi.org/10.1029/2018JD029172, 2018.

Major Comments:

1. The importance and significance of this study is not very persuasive. Only removing the interference of the stationary waves, I find it is hard to find any novelty of the results. The authors might add more discussion about the possible application of this new methods. Further, the stationary waves are much stronger than the travelling waves in their amplitudes. What is the ultimate aim of extracting the travelling the travelling wave amplitudes?

Response:

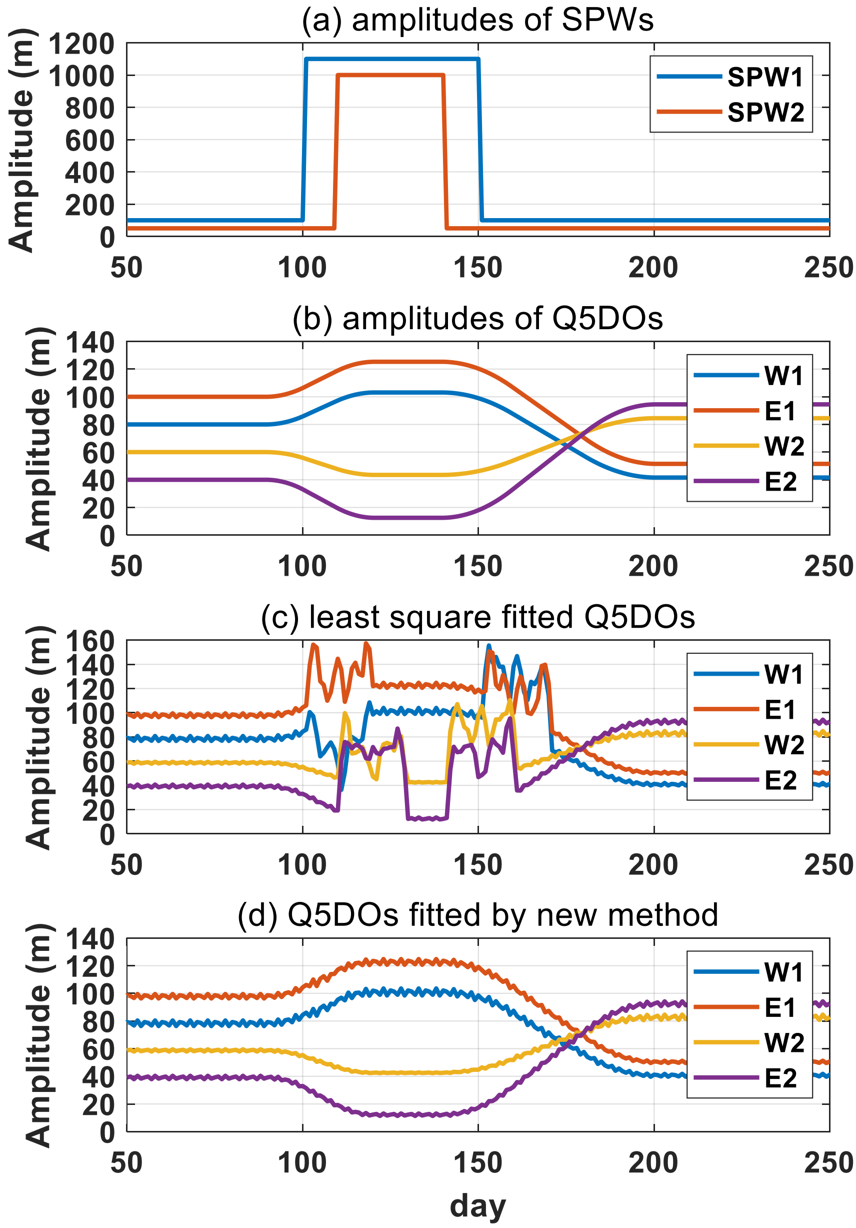
In the revised manuscript, we added the following discussions to explain the importance of this study and the possible applications of this new method.

"Generally, the TPWs, including the Q5DOs, dominate in the mesosphere and lower thermosphere, which are enhanced seasonally during winter and spring times and largely control the neutral winds and temperatures in the middle atmosphere (e.g., Gong et al., 2018, 2019; Pancheva et al., 2018; Yamazaki et al., 2020, 2021). The vertical and latitudinal propagation of the TPWs can also transport energies and lead to couplings on a global scale (e.g., Koushik et al., 2020; Ma et al., 2022). Thus, extracting the real amplitudes of the traveling waves is also important to reveal the characteristics in the mesosphere and the vertical couplings in the middle atmosphere. Some extremely strong TPWs are found to be related to the occurrence of SSWs, but their trigger mechanisms have not been fully understood (e.g., Ma et al., 2020; Yamazaki et al., 2021). However, the rapid and large change of the SPWs during SSWs can lead to contaminations when deriving the real amplitudes of TPWs based on satellite observations or reanalysis data. The new method proposed in the present study can capture a more accurate variation in the amplitudes of TPWs than the old one. The new method is based on the examinations during SSWs due to the assumption that a rapid and large change in SPWs is usually observed during SSWs. Nevertheless, the new method can also be used to extract the amplitudes of TPWs in the mesosphere during other seasons and cases, such as the spring final warmings and other disturbances in stratospheric vortices. Based on the new method, the common feature of the TPWs revealed by satellite observations in the mesosphere and lower thermosphere can be reevaluated, and the trigger mechanism of the mesospheric TPWs during SSWs can be further understood."

2. The difference between the old method and the new method is not very evident, especially for the synthetic method. If the authors have to present an example, why not use the real observation? The example shows that the curves extracted have some sawteeth, which might be a problem.

Response:

Since the rapid change in the amplitudes of SPWs was not given in a very large value, the differences between the old method and the new method shown in the simulations were not very evident. If we set a very large value in the rapid change SPW amplitudes, the fake amplitudes obtained from the old method will be significantly large (see the revised Figure 3).



Revised Figure 3. Simulations of the new fitting method based on synthetic data, which include (a) SPW1 and SPW2 and (b) westward and eastward Q5DOs with zonal wavenumber of 1 and 2. The phase of SPW1, SPW2, and W1, E1, W2, and E2 Q5DOs are respectively set as 0, $\pi/6$, $-\pi/4$, $\pi/5$, $-\pi/4$, and $\pi/3$. (c) Daily amplitudes of the fitted Q5DOs obtained from the original least square fitting method. (d) Daily amplitudes of the fitted Q5DOs obtained from the new fitting method.

Besides, we use the synthetic data instead of a real observation as an example to illustrate this issue, because we cannot determine 1) when the SPWs have a rapid and large change in the observational data; 2) how large the SPW amplitudes changed; 3) what the real amplitudes of Q5DOs in the observational data are. The use of the synthetic data will also provide us an opportunity to examine the effectiveness of the new method and to quantitively understand the limitation of the method.

In the revised manuscript, we added explanations for the sawtooth-shaped points. "Note that some sawtooth-shaped points can be seen in the fitting results in Figures 1, 2, and 3. The sawtooth-shaped points are caused by removing the linear declination on the time series. This process needs to be done in both original and new methods to eliminate the effect of seasonal trends in the observational data on the fitting of Q5DOs. The sawtooth-shaped points can be eliminated in the simulation by not removing the seasonal trends, but we keep it in both original and new methods in the simulations in order to be consistent with the processes in dealing with the observational data."

3. I am more concerned about the stratosphere. The amplitudes of the decomposed stationary waves and travelling waves in the stratosphere is more interesting, because SSWs occur in the stratosphere.

Response:

SSW does occur in the stratosphere, while large amplitudes of TPWs during SSWs are not observed in the stratosphere but the mesosphere and lower thermosphere in the geopotential height data. The TPW amplitudes are not shown below 10 hPa in the geopotential height observations because their amplitudes are at the noise level (below 20 m), this feature has been widely reported in previous studies (e.g., Yamazaki et al., 2021; Yamazaki & Matthias, 2019; Qin et al., 2019; Pancheva et al., 2018). In addition, the rapid and large change in the amplitudes of SPWs in the geopotential height data are usually found in the mesosphere (e.g., Lu et al., 2018), which has a limited influence on the variations of TPWs in the lower stratosphere. Thus, the mesospheric TPWs observed in the geopotential height data is generally a response to the SSW, but with limited impacts on the stratosphere due to their small amplitudes.

4. The origins of the stationary waves and travelling waves are worth mentioning in the paper. After reading, I did not find any information about the possible generation mechanism of the travelling and stationary waves in the middle atmosphere. Do all of them come from the troposphere? Is there any other mechanism of generating the travelling and stationary waves in the stratosphere and mesosphere?

Response:

Thank you for your suggestion. In the revised manuscript, we added the following discussions.

"The SPWs and TPWs can be both captured in the mesosphere region and their origins have been reported in some previous studies. The mesospheric SPWs are usually believed to be related to the upward wave signals from the troposphere and the lower stratosphere which rely on the structure of the polar vortex (e.g., Harvey et al., 2018).

In addition, wave-wave interactions, gravity wave forcing, and auroral heating can also generate the mesospheric SPWs (e.g., Lu et al., 2018; Xu et al., 2013; Smith, 2003). The mesospheric TPWs are generally considered as the result of atmospheric instabilities and many recent studies have noticed the relationship between extremely strong TPWs and SSW events (Liu et al., 2004; Ma et al., 2020; Yamazaki et al., 2021). The mesospheric TPWs during SSWs can be also secondarily generated in situ by wave-wave interactions (e.g., Xiong et al., 2018; Wang et al., 2021). Nevertheless, the trigger mechanisms of mesospheric TPWs are still not fully understood due to a lack of long-term and high-resolution observational data in this region. Thus, satellite observations are widely used to reveal the feature of mesospheric TPWs. However, as indicated by our simulations, the previous studies have ignored the effect of rapid and large changed SPWs when calculating the variations of TPWs during SSWs."

Harvey, V. L., Randall, C. E., Goncharenko, L., Becker, E., & France, J.: On the upward extension of the polar vortices into the mesosphere. Journal of Geophysical Research: Atmospheres, 123(17), 9171–9191. https://doi.org/10.1029/2018JD028815, 2018.

Smith, A. K.: The origin of stationary planetary waves in the upper mesosphere. Journal of the Atmospheric Sciences, 60(24), 3033–3041. https://doi.org/10.1175/1520-0469(2003)060<3033:TOOSPW>2.0.CO;2, 2003;

Xu, J., Smith, A. K., Wang, W., Jiang, G., Yuan, W., Gao, H., Yue, J., Funke, B., López-Puertas, M., Russell, I. I. I., & M, J.: An observational and theoretical study of the longitudinal variation in neutral temperature induced by aurora heating in the lower thermosphere. Journal of Geophysical Research: Space Physics, 118, 7410–7425, 2013;

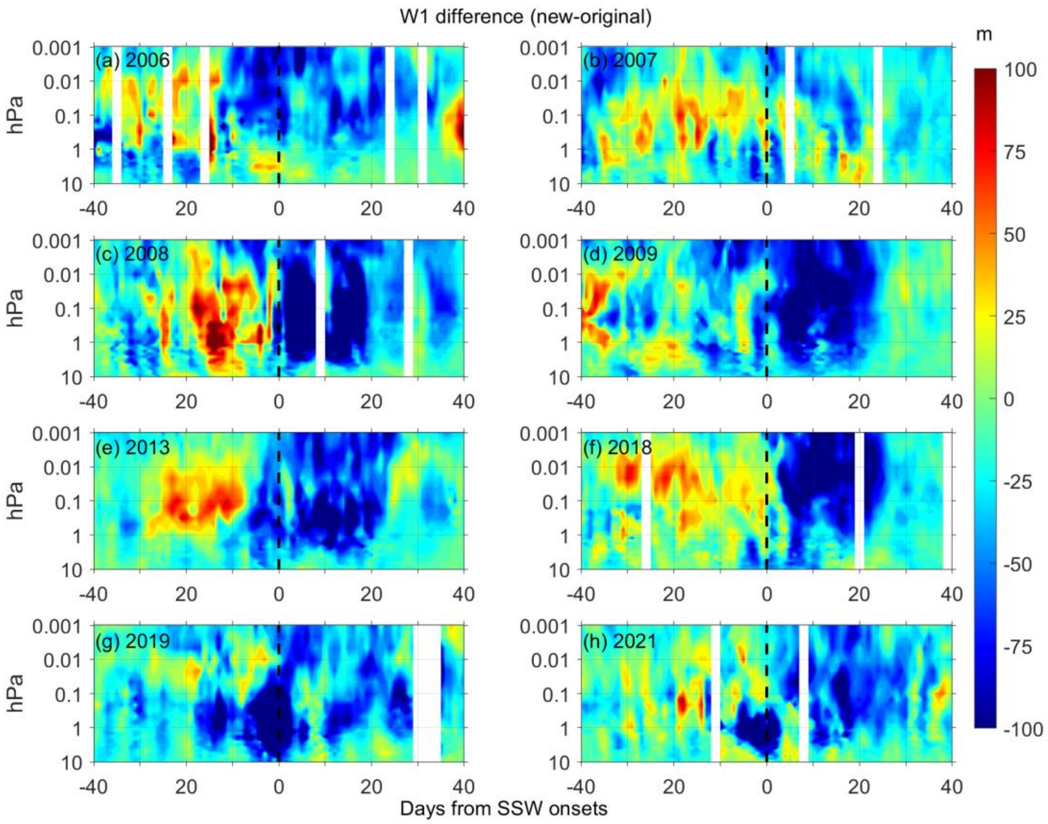
Lu, X., Wu, H., Oberheide, J., Liu, H.-L., & McInerney, J. M.: Latitudinal double-peak structure of stationary planetary wave 1 in the austral winter middle atmosphere and its possible generation mechanism. Journal of Geophysical Research: Atmospheres, 123, 11,551–11,568. https://doi.org/10.1029/2018JD029172, 2018.

Xiong, J., Wan, W., Ding, F., Liu, L., Hu, L., & Yan, C.: Two day wave traveling westward with wave number 1 during the sudden stratospheric warming in January 2017. Journal of Geophysical Research: Space Physics, 123, 3005–3013. https://doi.org/10.1002/2017JA02517, 2018.

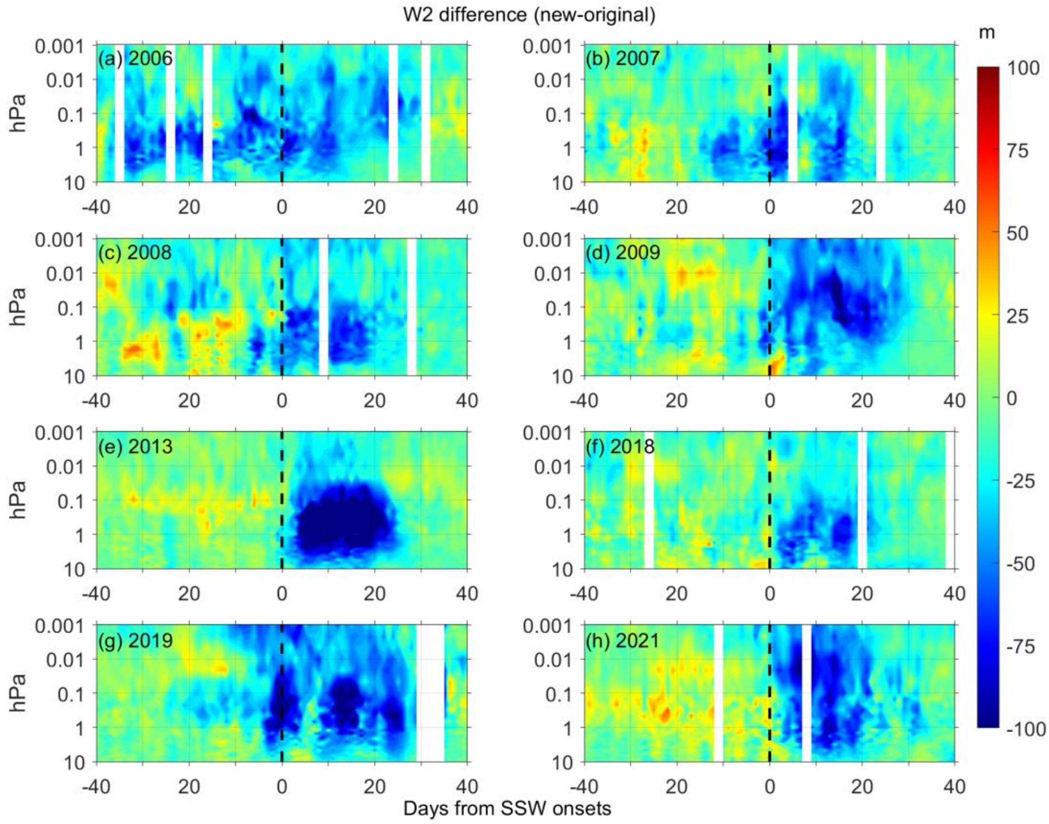
5. The robustness of the results is a big problem. Can you provide any test for the composite difference?

Response:

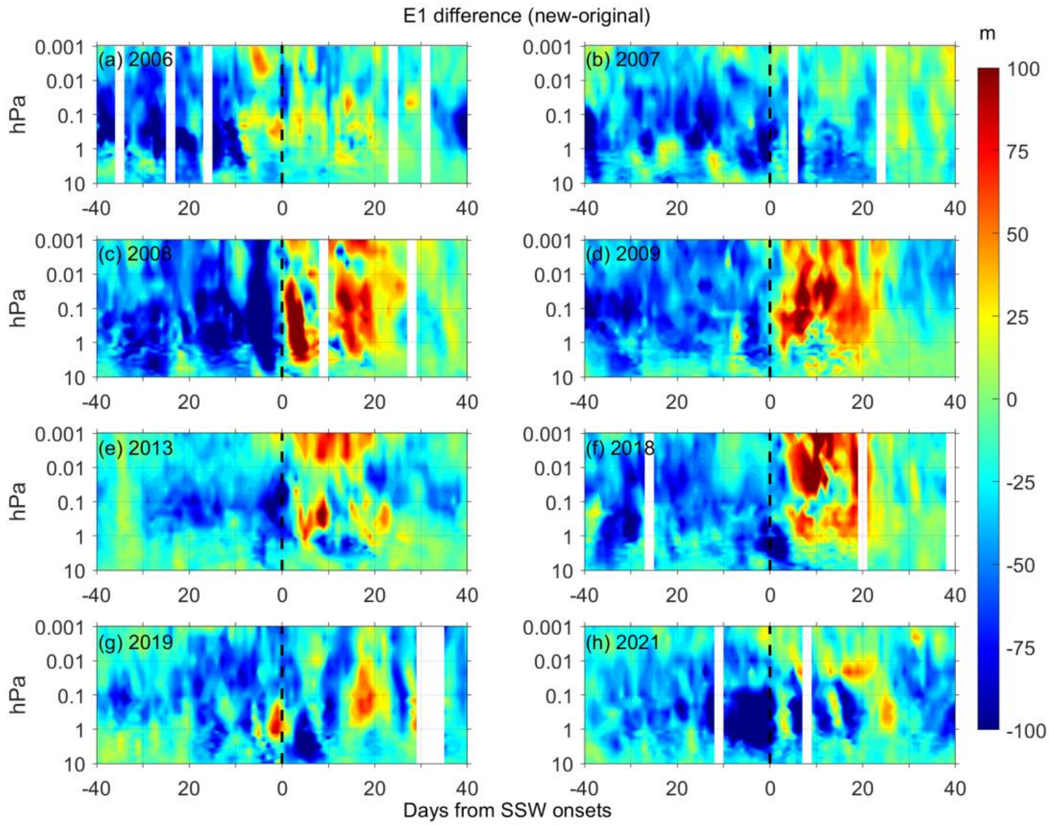
Thank you for your suggestion. Since the temporal and altitudinal variations of the Q5DOs are different during different SSWs, in the revised manuscript, we removed the composite analysis and presented the results separately during each case (see revised Figures 6-9).



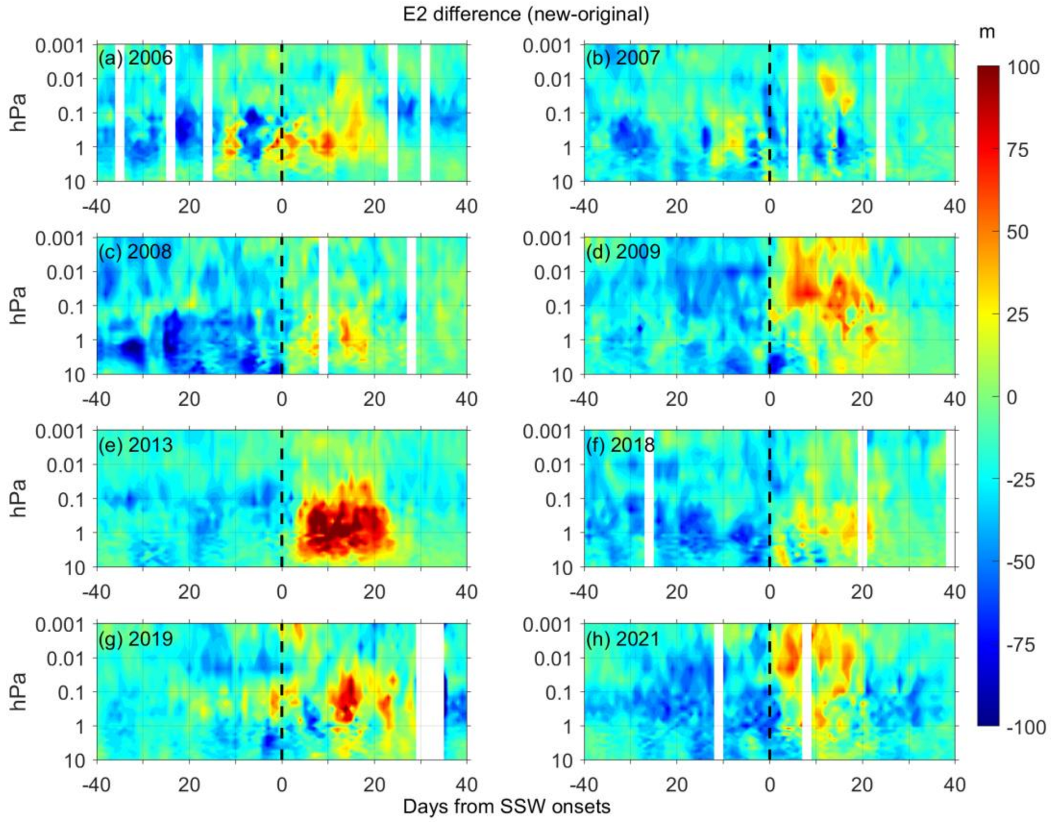
Revised Figure 6. The differences in the fitted W1 Q5DO amplitudes between the new and original methods during 8 major SSWs since 2006 (from a to h). Contour steps are 5 m.



Revised Figure 7. Same as Figure 6 but for the W2 component.



Revised Figure 8. Same as Figure 6 but for the E1 component.



Revised Figure 9. Same as Figure 6 but for the E2 component.

Specific Comments:

1. L46: This review paper was published in 2021. Changed to "Baldwin et al., 2021"

Response:

We made the change.

2. L47: two temperatures appear in this phrase, consider to rephase this sentence.

Response:

The first "temperature" has been removed in the revised manuscript.

3. L54-56: There are too many publications discussion this point. Suggest to add more recent ones.

Response:

We have added more publications in the revised manuscript (Harada and Hirooka, 2017; Liu et al., 2019; White et al., 2021).

Harada, Y., and Hirooka, T.: Extraordinary features of the planetary wave propagation during the boreal winter 2013/2014 and the zonal wave number two predominance. Journal of Geophysical Research: Atmospheres, 122(21), 11374–11387. https://doi.org/10.1002/2017JD027053, 2017.

Liu, S.-M., Chen, Y.-H., Rao, J., Cao, C., Li, S.-Y., Ma, M.-H., and Wang, Y.-B.: Parallel Comparison of Major Sudden Stratospheric Warming Events in CESM1-WACCM and CESM2-WACCM. Atmosphere, 10, 679. https://doi.org/10.3390/atmos10110679, 2019.

White, I. P., Garfinkel, C. I., Cohen, J., Jucker, M., and Rao, J.: The impact of split and displacement sudden stratospheric warmings on the troposphere. Journal of Geophysical Research: Atmospheres, 126, e2020JD033989. https://doi.org/10.1029/2020JD033989, 2021.

4. Figure 1. Please add the axis title for the x-axis. There are some sawtooth-shaped points for the extracted curves in Figure 1c, 1d. Can you present some explanation. Is there any method to remove those sawteeth in those plots?

Response:

Thank you for your suggestion. We have added the axis title and an explanation for the sawteeth in the revised manuscript.

“Note that some sawtooth-shaped points can be seen in the fitting results in Figures 1, 2, and 3. The sawtooth-shaped points are caused by removing the linear declination on the time series. This process needs to be done in both original and new methods to eliminate the effect of seasonal trends in the observational data on the fitting of Q5DOs. The sawtooth-shaped points can be eliminated in the simulation by not removing the seasonal trends, but we keep it in both original and new methods in the simulations in order to be consistent with the processes in dealing with the observational data."

5. L180: this criterion does not suitable for the … => …is not…

Response:

We have changed this sentence to "this criterion is not suitable for the analysis of Q5DOs with different phases."

6. Figure 2b, Figure 3c, 3d: Similar problem as for Figure 1.

Response:

Please see our response to the specific comment 4.

7. L310: The SSWs before 2013 were also studied in Liu et al. (2019; doi: 10.3390/atmos10110679) and Rao et al. 2019 (Table 1; doi: 10.1029/2019JD030900)

Response:

We have added these publications in the revised manuscript.

8. L336: Because we did not have the observations of the decomposed wave amplitudes, it is not strictly true to regard the results from the new methods as the baseline. But there is possibility that the amplitude in the old method is overestimated.

Response:

Thank you for your suggestion. In the revised manuscript, we modified this sentence as "The amplitudes of W1 Q5DOs after the onset of 2008 SSW might be overestimated by the original least square fitting method.”

9. L352-353: If we use the old method as the baseline, the conclusion is reversed. The authors should be careful and cautious to summarize. I suggest to add more discussion. If there are some observed amplitudes for all waves, this comparison is more meaningful. Using the new method as the baseline, the old method is hypothesized to have problems. This bias might be not true.

Response:

Thank you for your suggestion. As you mentioned above, we did not have the observations of the decomposed wave amplitudes. Comparisons are made to reveal the differences between the two methods and to propose the possibility of contaminated amplitudes obtained by the original method. In the revised manuscript, we modified this sentence as:

“However, results from the new method after the onset of 2013 SSW suggest that based on the original least square fitting method, the amplitudes of W2 Q5DOs might be overestimated and the amplitudes of E2 Q5DOs may be underestimated.”

10. Figure 6: Because this is a composite picture, I suggest to add the significant test. The largest problem of the paper is lack of test.

Response:

Please see our response to the major comment 5.