Response to Anonymous RC #2 's Comments,

This paper examines the semi-annual oscillation (SAO) of temperature in the upper troposphere and lower stratosphere (UTLS) using the data from satellite observations, two reanalyses, and model simulations. Furthermore, this paper investigates the thermodynamic components which affect the SAO and find the connection between SAO in the surface and SAO in the UTLS. Overall, this is an interesting and well written paper. The manuscript contains material that is of interest to ACP readers. However, there are a few issues that I would like to see addressed before it is suitable for publication.

Response：We would like to sincerely thank the referee for the constructive comments and suggestions which helps to improve the manuscript significantly. Following the reviewer's comments/suggestions, we have revised the manuscript substantially. Please note that the manuscript is also altered according to the other 1 reviewer's comments and suggestions and all figures have been revised. More details can be found in the point-by-point responses as shown below.

Specific comments:

• Figure 1, Figure 2, and Figure 8

It is really difficult to understand Figure 1, Figure 2, and Figure 8. I was confused the first time that I read the paragraphs regarding these three figures. The color shading in the figures seems to indicate some variable related to the time period from the unit 'dBmonth' in the figures. However, the texts related to these figures describe the color shading as the strength or magnitude of temperature SAO. The PSD method is briefly mentioned in the end of Section 1. Since several figures and a lot of the results in the manuscript are based on the PSD method, it might be worth introducing the PSD method in more detail and explaining the meaning of 'dBmonth' to guide the readers. If possible, it might be better to connect 'dBmonth' with 'Kelvin' unit.

Response：We apologize for the confusing information. The unit should be K^2 month and we have corrected the unit in the figures. We add more description in lines 85-86.

• L138-L139

I'm not sure how the result is consistent with the results from Fueglistaler et al. (2009)?

Response：As described in the manuscript, there is also no significant annual cycle in the tropical upper troposphere in Fueglistaler et al. (2009). However, our research mainly focuses on the SAO, and we decide to delete this sentence after careful consideration.

• L154-L160

The UTLS SAO is significant almost in the whole zonal band in the middle latitude. Monsoon might amplify the amplitude of the SAO inside of some monsoon regions, but it does not suggest the direct connection between monsoon and the UTLS SAO outside of monsoon regions from Figure 2. Especially, the authors use Asian summer monsoon as an example to prove the influence of the transportation of water vapor and its condensation on the SAO. Does this also apply in the connection between Australian region and SAO? Maybe the authors should clarify the statement.

Response：Thank you very much for your suggestion. We have modified the relevant content about the monsoon. A significant part in the SH represented by MERRA2 model cannot be explained by ANA, dynamical and moist process, which indicates that the budget for the SH is not as reliable as the NH. Therefore, we use the energy budget of the simulation to analyze the Australian region. As shown in Fig. R4, the moist related heating rates are higher over the Australian region than other regions in the same latitude, indicating that the transportation of water vapor and its condensation also influences the SAO in the southern hemisphere. At the same time, the dynamical heating rates are also larger over the Australian region than other regions in the same latitude. Therefore, the more significant SAO signal over the Australian region is related to both moist and dynamical processes.
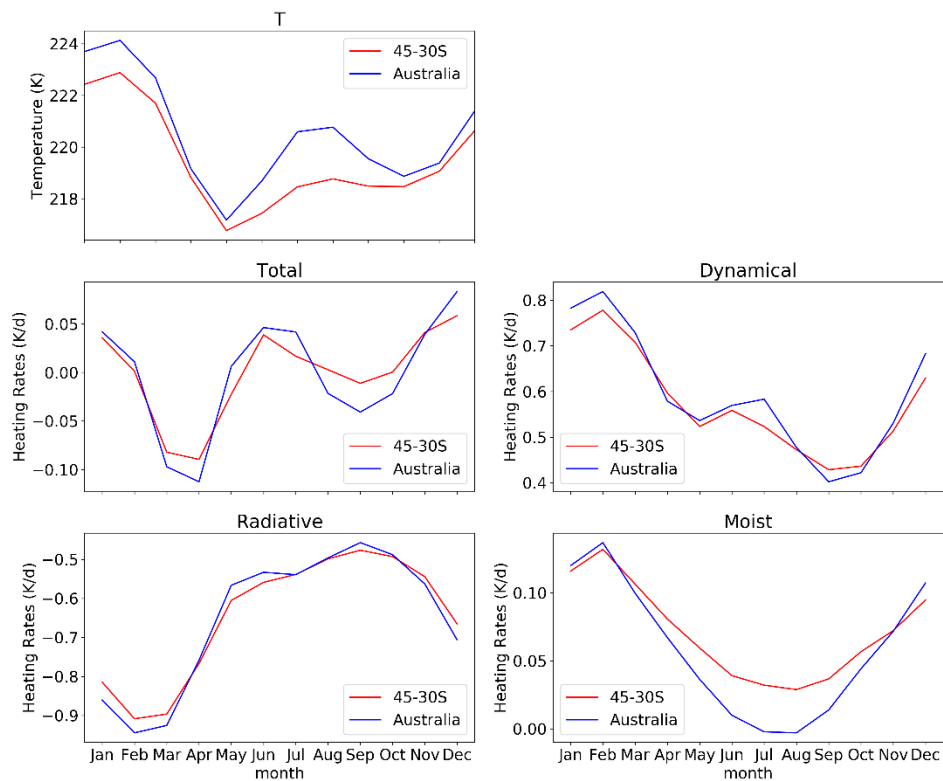
Fig. R4 Annual cycle of the zonal mean temperature (T), total heating rates (Total), dynamical heating rates (Dynamical), radiative heating rates (Radiative), and moist heating rates (Moist) at 200hPa averaged around the Australian region with blue lines (45°S-30°S, 30°E-180°E) and global region with red lines (25°N-45°N) using MERRA2 data. The total heating rates equal the sum of analyzed, dynamical, radiative, and mois theating rates.

• The authors mentioned "We then mainly focus on the SAO in the UTLS region (250-175hPa) in mid-latitudes (22.5 °-42.5°) hereafter in this study." in L142-143. However, almost all the results are about the region in 32.5 °-42.5° since Section 3.2. An explanation is required for taking different regions.

Response：Sorry for the mistake. We mainly focus on the region 32.5 °-42.5°. We have corrected the sentence.

• L207-L209 and Figure 6

Response：Thank you for your suggestion. We put Figure 6 to the supplement in the revised manuscript.

• L219

"by the -vTy term", should it be "by the eddy term"? Please check

Response：Yes, it should be "by the eddy term". We have corrected it.

• L236-L238

The nearly concurrent UTLS-SAO in the two hemisphere can explain the similar correlation patterns between SH and NH mid-latitude with SSTs, but not between SH/NH mid-latitude and tropical UTLS-SAO with SSTs.

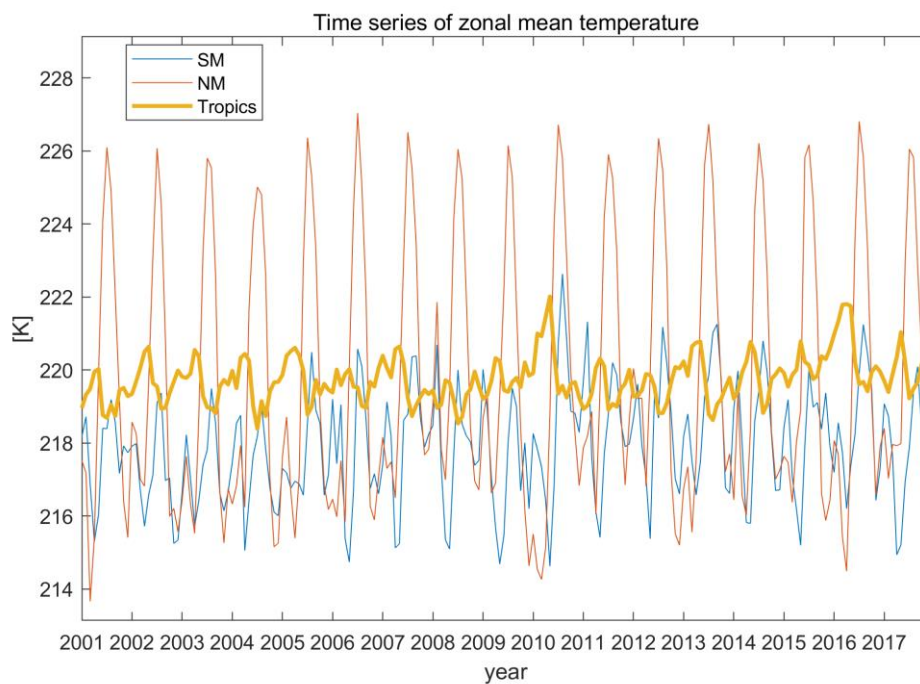Response：Yes, the tropical UTLS-SAO and SH/NH mid-latitude UTLS-SAO is out phase (Fig. R5). We correct the sentence.

Fig. R5 Time series of ERA5 zonal mean temperature at 200hPa averaged around the SM(32.5 °S-42.5 °S, 20 °E-100 °E), NM(32.5 °N-42.5 °N, 20 °E-100 °E) and tropics (5 °S-5 °N, 20 °E-100 °E).

"However, while the...in extra-tropics is important.", I would suggest to change

this sentence as "While the SST-SAO is removed globally, the SAO in the tropical upper-middle troposphere (500-175 hPa) is not significant. However, if the SST-SAO is removed only in the tropics, the upper troposphere SAO in the tropics is still significant, which indicates that the upper-middle troposphere SAO in the tropics is significantly influenced by the SST-SAO in the extra-tropics".

Response：Thank you very much for your suggestion. We have changed the sentence.

"Such reduction of..." Maybe the reduction of the absolute magnitude is more

evident in the SH/NH compared to that in the tropics. The relative reduction seems comparable given the weak SAO in tropics in the control simulation.

Response：We further checked the relative difference between different model simulations (Fig. R6). The relative reduction is weaker in the tropics compared to those in SH/NH in the focusing region (250-175 hPa).
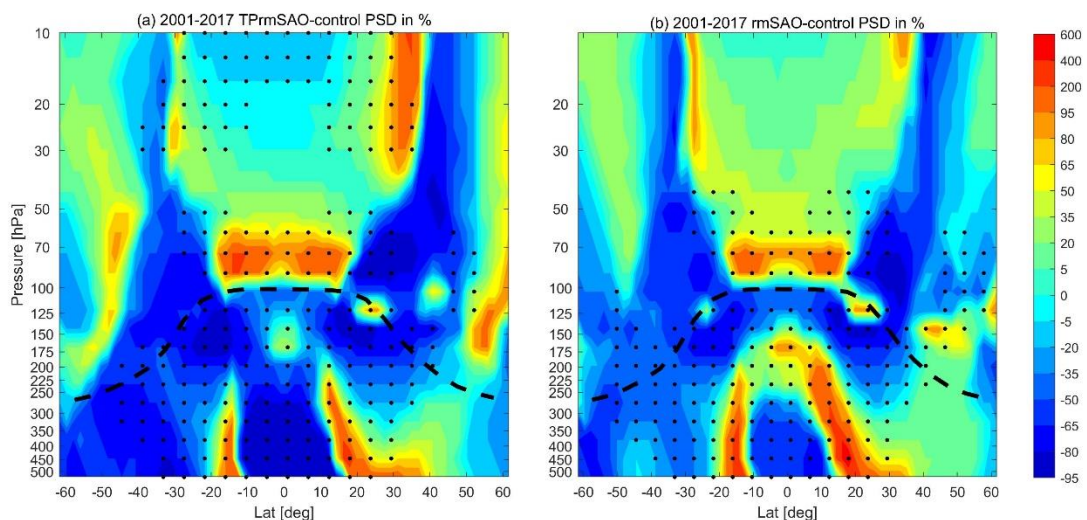

Fig. R6 (a) The relative difference of SAO PSD in % between the TPrmSAO and the Control simulations (TPrmSAO - Control) /Control for the period 2001-2017. (b) Same as (a), but for the relative difference between the rmSAO and the Control simulations (rmSAO - Control)/Control in %. The black dots mark area with significant

difference of the two time series at 95% level based on t-test. The dashed black lines mark the tropopause height calculated with GNSS RO data.

• L258-L260

This sentence just repeats the conclusion in L255-L256. Additionally, it should be "Figure1d, 8a-b"

 Response：Thank you for your reminder. We delete this sentence.

• L281-L282 and L308

The modification in the summer moist heating is really small compared to that in the dynamical heating and radiative cooling for SH. I am not sure it is appropriate to make this conclusion for SH.

Response：Yes, the moist heating is really small compared to that in the dynamical heating and radiative cooling, but it shows good agreement with SAO. After careful consideration, we decide to add dynamical heating in these sentences. The modification should be related to moist heating , radiative cooling and dynamical heating.

Technical comments:

• L8

"the winter time ... the summer time maximum"–> "the austral winter time ... the austral summer time maximum"

To avoid the confusion, please check and add "austral" in front of winter and summer for SH in the whole manuscript

Response：Thank you for your suggestions. We have added them in the manuscript.

• L82

Details information –> Detailed information

Response：Corrected.

• L185

Therefore, the are –> Therefore, there are

Response：Corrected.

• L187

in Figure 5 –> Figure 5a

Response：Corrected.

• L190

Figure S4 –> Figure S4a

Response：Corrected.

• L216

Abalos et al. (2013) –> (Abalos et al., 2013)

Response：Corrected.

• L231

"between the tropical(5°S-5°N), SH/NH mid-latitude UTLS-SAO and the SST-SAO" might be better to change as "between the SST-SAO and the UTLS-SAO over the tropical(5°S-5°N) and the SH/NH mid-latitude"

Response：Corrected.

• L236

Pacific, whereas the SST-SAO are most pronounced (Figure S6) –> Pacific (Figure S6a), whereas the SST-SAO are most pronounced (Figure S5a)

Response：Corrected.

• L256

31% for NH and 55% for SH –> 31% for NHM and 55% for SHM

Please check and replace NH/SH with NHM/SHM through the whole manuscript when it is necessary, and add abbreviation about NHM/SHM in proper place ahead

Response：Thank you for your suggestions. We have checked them and corrected them in the manuscript.

• L263

in Figure 9 –> in Figure 9a

Response：Corrected.

• L267

SH (Figure 9b) –> SH (Figure 9b) compared to that in the NHM

Response：Corrected.

• L286-L287

except for a relatively large difference with other data sets in the tropical region –> except in the tropical region

Response：Corrected.