Response to Anonymous RC #1 ’s Comments,

The paper by Shangguan and Wang is an interesting piece of work that addresses the semiannual oscillation (SAO) in the UTLS. This topic is of relevance because of its potential to provide predictive capabilities on seasonal and subseasonal time scales. Another merit of this work is that the SAO in the UTLS region has not been topic of many studies so far. The authors investigate the UTLS SAO in temperatures of two reanalyses, temperatures observed by GNSS RO, and simulations with WACCM. In a sensitivity simulation, the influence of the SST SAO on the UTLS SAO is examined.

The topic of this paper falls into the scope of ACP and is of interest to its broad readership. Generally, the paper is well written. The paper is therefore recommended for publication in ACP after addressing my mainly minor comments that are given below.

Response：We would like to sincerely thank the referee for the constructive comments and suggestions. Following the reviewer’s suggestion, we have substantially revised the manuscript. Please note that the manuscript is also altered according to the other reviewer’s comments and suggestions. More details can be found in the point-by-point responses as shown below.

Main Concern:

The authors claim that regions where the UTLS SAO is strongest would coincide with the global monsoon regions, and it would therefore indicate that the UTLS SAO is related to the monsoon processes. However, this is not supported by the figures shown in the paper. The UTLS SAO has even minima in the monsoon regions. It maximizes roughly at 35N and 35S, and in some regions near the equator.

Response：Thank you very much for the very helpful comment. We agree to the reviewer that the UTLS SAO does not coincide with the monsoon regions. Based on further analysis, we think that the strong SAO signals over that region are likely related to both moist and dynamical processes. More detailed discussions can be seen in our response to your specific comments (10). The relevant content has been modified after careful consideration.

Specific comments:

(1) l.22: This is not entirely correct: The MA-SAO is a complex interplay of momentum advection, planetary waves from the extratropics, and vertically propagating waves (both global-scale waves and small-scale gravity waves) (Hamilton and Mahlmann, 1988; Richter et al. (2006); Ern et al. (2015, 2021)).

Hamilton, K. and Mahlmann, J. D.:General Circulation Model simulation of the semiannual oscillation of the tropical middle atmosphere, J. Atmos. Sci., 45, 3212-3235, 1988.

Ern, M., Preusse, P., and Riese, M.: Driving of the SAO by gravity waves as observed from satellite, Ann. Geophys., 33, 483-504, https://doi.org/10.5194/angeo-33-483-2015, 2015.

Ern, M., Diallo, M., Preusse, P., Mlynczak, M. G., Schwartz, M. J., Wu, Q., and Riese, M.:The semiannual oscillation (SAO) in the tropical middle atmosphere and its gravity wave driving in reanalyses and satellite observations, Atmos. Chem. Phys., 21, 13763-13795, https://doi.org/10.5194/acp-21-13763-2021, 2021.

Response: Thank you very much. We have corrected the sentence in the introduction according to your suggestion.

(2) l.23-36: There is some more work that should be mentioned in the introduction: In a recent paper, Yang and Wu (2022) relate the semiannual surface air response to changes in the oceanic mixed layers.

Yang, F., and Wu, Z.: On the physical origin of the semiannual component of surface air temperature over oceans, Climate Dynamics, https://doi.org/10.1007/s00382-022-06199-z, 2022.

Bracegirdle (2011) showed that at latitudes between 50S and 65S the SAO in sea level pressure is coupled with the stratospheric circulation, and correlations are found over a large altitude range in the troposphere and stratosphere. In particular, a downward influence from the stratosphere is significant in late summer/early autumn.

Bracegirdle, T. J.: The seasonal cycle of stratosphere-troposphere coupling at southern high latitudes associated with the semi-annual oscillation in sea-level pressure, Climate Dynamics, 37, 2323-2333, doi:10.1007/s00382-011-1014-4, 2011.

Response：Thank you very much. We have added suggested references in the introduction.

(3) l.55: Also harmonics of the annual cycle could result in a significant contribution to the semiannual signal. For example, if the annual variation is not a sinus-like variation, but instead consists of only a narrow peak, a whole series of harmonics would be needed to describe its temporal variation. Therefore you should emphasize that the SAO variations that you are investigating are more sinus-like, as you show in Fig.3.

Response：Thank you for your suggestions. We have modified the sentence.

(4) l.67: GNSS-RO temperatures of the wetPrf product may not be fully reliable anymore in the troposphere. For the wetPrf retrieval usually ECMWF analysis temperatures in lower resolution are used as input, and then a 1DVar retrieval is performed to disentangle the effect of humidity and temperature on RO bending angles in the troposphere (Kursinski et al., 2000). Therefore it is not completely clear to which degree the wetPrf product and ECMWF analyses are independent (perhaps this is the reason why GNSS RO and ERA5 agree so well). I guess, you are using GNSS-RO temperatures at altitudes above ~5-8km where they should

still be reliable. But still you should add a cautionary note for altitudes below ~5-8km, where biases could exist (see Xu et al., 2017).

References:

Kursinski, E. R., Healy, S. B., and Romans, L. J.: Initial results of combining GPS occultations with ECMWF global analyses within a 1DVar framework, Earth Planets Space, 52, 885-892, 2000.

Xu, G., Yue, X., Zhang, W., and Wan, X.: Assessment of Atmospheric Wet Profiles Obtained from COSMIC Radio Occultation Observations over China, Atmosphere, 8, 208, doi:10.3390/atmos8110208, 2017.

Response：Yes, we use wetPrf data between 500 and 10 hPa (above 5 km) and we have added the reference and the cautionary note in the manuscript.

(5) l.110: Please note that w* is not the pressure vertical velocity! Please mention the conversion between w* and omega* that you are using!

Response：Thank you very much for the reminder. We have changed the corresponding symbols and mentioned the conversion in the manuscript.

(6) l.113: Here, you should also mention the cooling by upwelling in the tropics.

Response：We have added it to the manuscript.

(7) l.117/118: Please clarify! Did you use both resolved and parameterized terms?

Response：Yes, we use both resolved (the dynamical heating rates) and parameterized (the radiative and moist heating rates) terms which are provided by MERRA2 (Modeling, G., & Office, A. 2015).

Reference:

Modeling, G., & Office, A. (2015). MERRA2 tavgM_3d_tdt_Np: MERRA2 3d, assimilation, monthly mean, temperature tendencies (p-coord, 0.625x0.5l42), version 5.12.4, greenbelt, MD, USA: Goddard space flight center distributed active archive center (gsfc daac) accessed: January 2021. doi: 10.5067/VILT59HI2MOY

(8) It is not clear to me what the unit "dBmonth" means that is used in Figs.1, 2, and 8. For a temperature response the unit Kelvin should appear somewhere!

Response：Sorry, it should be K^2 month and we have corrected the unit in figures.

(9) l.145: The good agreement between ERA5 and GNSS RO could also be an effect of using ECMWF temperatures as input for the wetPrf retrieval.

Response：Yes, GNSS RO WetPrf data use low-resolution ECMWF ERA-Interim profiles as a background. However, the temperature profiles are further derived by the 1DVAR technique (Wee and Kuo 2015). We have compared the GNSS RO temperature data in the UTLS with ERA-Interim, ERA5 and MERRA2 reanalyses in our previous study (Shangguan et al. 2019). The results show that the GNSS RO temperature in the UTLS has the best agreement with ERA5, rather than ERA-Interim, which are as used as inputs for 1DVAR.

Reference:

Wee, T.-K. and Kuo, Y.-H.: Advanced stratospheric data processing of radio occultation with a variational combination for multifrequency GNSS signals, Journal of Geophysical Research Atmospheres, 119, 11,011–11,039, 2015

Shangguan, M., Wang, W., and Jin, S.: Variability of temperature and ozone in the upper troposphere and lower stratosphere from multisatellite observations and reanalysis data, Atmospheric Chemistry and Physics, 19, 6659–6679, 2019

(10) l.154/155: Here you state that the largest SAO signal would be over the global monsoon regions. I disagree with this statement!

Having a look at Fig.2, the strongest signal is seen at 35deg in both hemispheres, as well at places near the equator, and not in the monsoon regions!

The monsoon regions are located around 15N and 15S, see:

https://www.wcrp-climate.org/documents/monsoon_factsheet.pdf or:

Geen, R., Bordoni, S., Battisti, D. S., and Hui, K: Monsoons, ITCZs, and the concept of the global monsoon, Reviews of Geophysics, 58, e2020RG000700. https://doi.org/10.1029/2020RG000700, 2020.

At latitudes of 15deg the opposite is found in Fig.2: over the monsoon regions, there are minima of SAO PSD, and the signal is mostly insignificant!

Particularly, for North America the maximum SAO PSD is found over the Great Lakes, and not over Central America. Also in Eurasia, the maximum is between 35N and 45N, away from the monsoon region.

Perhaps it makes sense to compare the locations of the SAO PSD maxima with the seasonal changes of the jet streams, but this is just a speculation.

Response：Thank you very much for your suggestion. We agree with the reviewer that the largest SAO signal is not over the monsoon regions. After a further check, we think the strong SAO signals over that regions are likely related to both moist and dynamical processes. As seen in Figs. R1 and R2, there are strong upward motion over south Asia but downward motion from north Africa to central Asia. The strong upwelling brings a large number of water vapor from the surface to the upper troposphere, which condenses there and heats the atmosphere at around 200 hPa. At the same time, the strong downwelling leads to dynamical heating over the regions from north Africa to central Asia. We have also checked the annual variation of the jet streams as the reviewer suggested (Fig.R3). The seasonal changes of U over the focused areas are weaker than in other regions, which implies that the strong SAO signals may not be related to the seasonal changes of the jet streams. We have modified the sentences in the manuscript carefully.

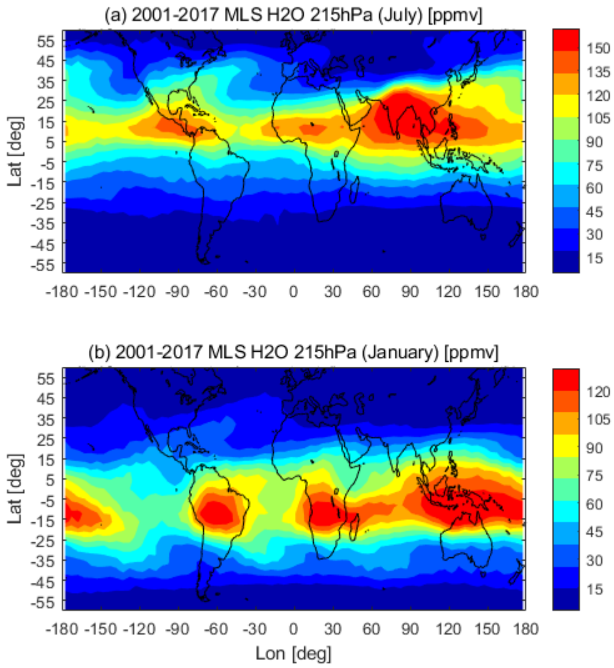

Figure R1. The July (a) and January (b) averaged water vapor mixing ratio in ppmv of 2005-2017 microwave limb sounder (MLS) at 215hPa.

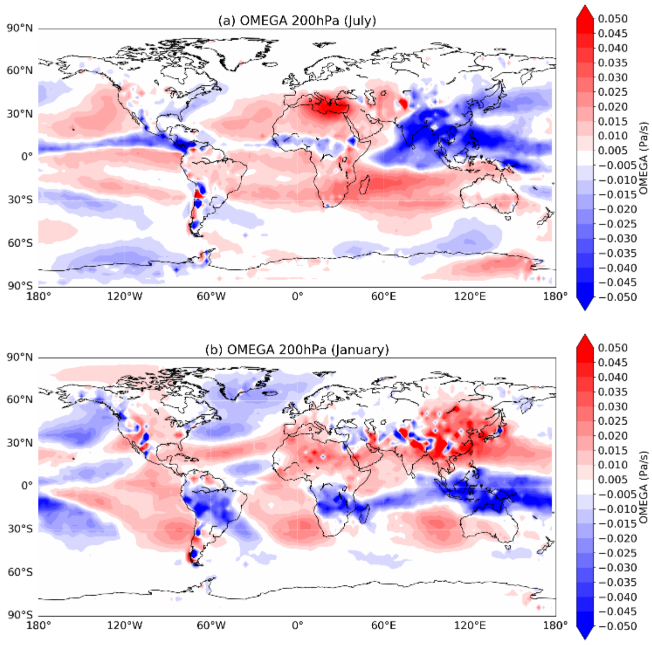

Figure R2 The July (a) and January(b) averaged vertical velocity in Pa/s of 2005-2017 ERA5 at 200hPa.

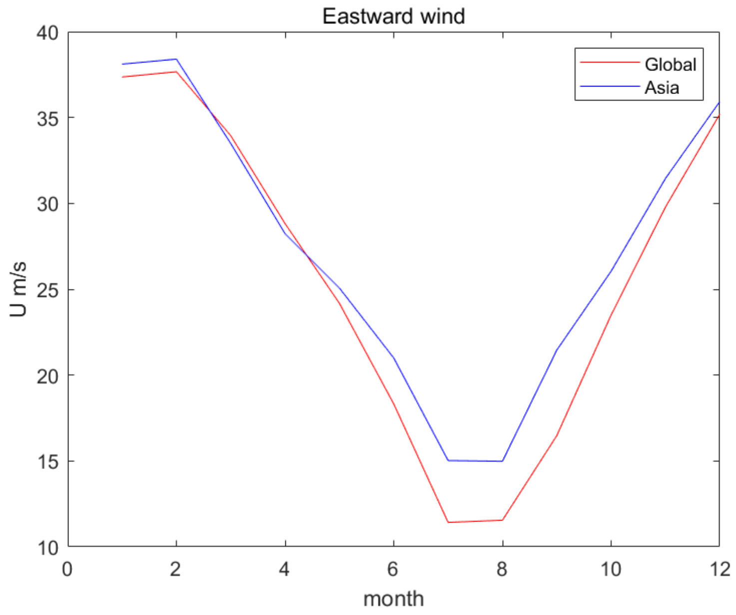

Fig. R3 Annual cycle of the zonal mean eastward wind (U) at 200hPa averaged around the Asia region with blue lines (25ºN-45ºN, 20ºE-100ºE) and global region with red lines (25ºN-45ºN) using MERRA2 data.

(11) Fig.4, Fig.6, and Fig.9: Please plot from Jan to Jan, and not from Jan to Dec, otherwise the seasonal variations do not look cyclic.

Further, the peak in Dec is not given much space so that it is easily overlooked.

Response： Thank you for your suggestions. We have renewed these figures.

(12) l.225-237: Can you briefly mention the mechanisms that lead to the SST-SAO, and whether there are global phase variations?

Response： Thank you for your suggestions. According to Yashayaev and Yveryaev 2001, the SST-SAO in tropical Pacific and the Atlantic oceans is related to semiannual cycle of solar radiation. The SST-SAO in the tropical Indian Ocean is related to the Indian monsoon (Hu et al. 2004): The strong solar radiation is related with less cloud warms the water in spring, which leads highest SST; After the onset of the Indian summer monsoon, the strong coastal upwelling and offshore advection of cold waters in response to strong monsoon winds cause the temperature drop; The stronger solar radiations warms the water again, which leads to the second highest SST during boreal autumn; The cold winter monsoon from Asian continent cause another falling phase of SST.

In the supplement, Figures S7a-c show the correlation coefficients between the tropical(5° S-5° N), SH/NH mid-latitude UTLS-SAO and the SST-SAO. Correlation coefficients between SH/NH midlatitudes UTLS-SAO and SST-SAO are all negative values while the coefficients are positive between topical UTLS-SAO and SST SAO. According to the result, there are global phase variations. We have added the corresponding content to the manuscript.

References

Yashayaev, I.M. and Zveryaev, I.I. (2001), Climate of the seasonal cycle in the North Pacific and the North Atlantic oceans. Int. J. Climatol., 21: 401-417. https://doi.org/10.1002/joc.585

Ruijin, Hu., et al. On the mechanism of the seasonal variability of SST in the tropical Indian Ocean. Adv. Atmos. Sci. 22, 451 (2005). https://doi.org/10.1007/BF02918758

(13) l.292/293: I do not agree with the statement that the SAO is strongest in the monsoon regions.

Response：We have deleted the sentence.

(14) l.299-301: This is not necessarily an effect of the monsoons. The summer thunderstorm season at midlatitudes would have the same effect.

Response：Thanks, we have deleted the monsoons.

Technical corrections:

Affiliations:

1: Informaiton -> Information

Wuhan,China -> Wuhan, China

Response：Corrected.

2: Science,China -> Science, China

Wuhan,China -> Wuhan, China

Response：Corrected.

l.24: maximum -> maxima

Response：Corrected.

l.54: significant test -> significance test

Response：Corrected.

l.54: diagnose the SAO -> diagnose whether the SAO

Response：Corrected.

l.62: 2008 and -> 2008, and

Response：Corrected.

l.72: whereas -> for this,

Response：Corrected.

l.79 significant test -> significance test

Response：Corrected.

l.82 Details information -> Detailed information

Response：Corrected.

l.85 Both reanalysis -> Both reanalyses

Response：Corrected.

l.110: with R is -> with R =

Response：Corrected.

l.122 MEERA2 -> MERRA2

Response：Corrected.

l.156:

signal overlies on the -> found in the

indicate that -> indicates that

Response：The sentence has been deleted according to your suggestions.

l.158, l.160: than other regions -> than in other regions

Response：Corrected.

Fig.3: labeling of the panels does not match with the figure caption, labeling is a-c-b-d, and not a-b-c-d

Response：Corrected.

l.180: two hemispheres -> the two hemispheres

Response：Corrected.

l.185: the are -> there are

Response：Corrected.

l.187: to show in -> and shown in

Response：Corrected.

l.188: Over all, -> Overall,

Response：Corrected.

l.192: Jannuary-February -> January-February

Response：Corrected.

l.207: but with -> but for the

Response：Corrected.

caption of Fig.7:

at 200 -> at 200 hPa

eddy , heating -> eddy, heating

Response：Corrected.

l.226: Easter Pacific -> Eastern Pacific

Response：Corrected.

l.247: with the Control simulation. -> with respect to the Control simulation.

Response：Corrected.

l.256: Figures 8c -> Figure 8c

Response：Corrected.

l.257: Figures 8d -> Figure 8d

Response：Corrected.

l.258: Compares the magnitude -> if we compare the magnitude

Response：Corrected.

l.259: in three model simulations -> in the three model simulations

Response：Corrected.

l.272: to three -> to the three

Response：Corrected.

caption of Fig.9:

The averaged of the extracted SAO singals -> The average extracted SAO signals

(SH) mid-latitudes -> (SH) mid-latitudes (b)

The blue, red -> The red, blue

Response：Corrected.

l.335 ???

In the theory of filter amplifires -> On the theory of filter amplifiers

Response：Corrected.

l.349: doi and page range missing for reference Gelaro et al. (2017)

Response：Added.

l.353: doi and page range missing

Response：The doi is added and there is no page for the reference.

units are missing in Figs. S2 and S5

Response：Added.

in Fig.S5 Panel (c) is not addressed in the figure caption

Response：Added.