Response to Reviewer #2's comments

First of all, we would like to thank the Reviewer #2's comments and suggestions, which improved significantly the presentations and interpretations of our revised manuscript. In the revised article, we have addressed all comments from the Reviewer. Our point-by-point responses to the Reviewer's comments are outlined below. The original comments are shown in italics and our responses are given in normal fonts.

The manuscript by Zhang et al. analyzes the influences of climate variations on long term O_3 trends in China and explores the linkage between O_3 and a dominant atmospheric circulation system, using a modeled tropospheric ozone dataset and two western pacific subtropical high (WPSH) indexes. They conclude that the effect of the WPSH on regional O_3 is attributed to the changes in air temperature, precipitation, and winds associated with the WPSH's intensity and positions. However, the discussion of EOF analysis is lack of sufficient explanation on the association of O_3 patterns with WPSH. The significance of this paper is not expound sufficiently. The author need to highlight this paper's innovative contributions in abstract and conclusions. Here list some of my main concerns.

Response: We thank the Reviewer's positive and encouraging comments which help us improve this article considerably. We have made every effort to address the Reviewer's comments and highlight the innovative contributions of this paper in revised Abstract and Conclusions.

Point-by-point responses：

1. *Climatologically, the WPSH activities with east-west expansion, and north-south movement significantly affect the daily, seasonal, interannual, and longer-term meteorological fields and climate variations over central and eastern China. Which temporal scale of WPSH exerts the most significant effect on tropospheric O_3 in daily, seasonal, interannual, and longer term variations? Please add more discussions on WPSH climatology and environment effects.*

Response: To address the Reviewer's comment, we have added corresponding discussions on the impact of WPSH on daily and short-term O_3 variations from previous studies and potential causes in revised Introduction (the last paragraph). We did not attempt to identify the influences of WPSH with different temporal scales on tropospheric O_3 but focused on interannual and long-term scale effect because daily and short-term WPSH effects on O_3 have been investigated in China previously. Rather, the influences of WPSH on interannual and longer term O_3 variations are almost unknown, which was the major objective of our study. In revised Introduction (last paragraph), we further emphasized this objective.

Following the Reviewer's comment, we have added detailed descriptions on WPSH climatology and its effect on O_3 variation in the beginning of revised section 2.2.

2. *There are the distinct patterns in spatial distribution of WPSH with most significant seasonal (sub-seasonal) variations. Why can leads the WPSH to lower O_3 levels in the Pearl River Delta (PRD) region (line 32)? There is a misleading on the relation between the WPSH and lower O_3 levels. How can WPSH affect the tropospheric O_3 over the Tibetan Plateau and Northwest China? It is suggested to focus the central and eastern China with the direct WPSH effect.*

Response: We thank the Reviewer to indicate the potential misleading in our analysis. Following the Reviewer's comment, we have rewritten the first paragraph of section 3.2 by adding following statements "The causes of the lack of statistically significant O_3 trend and negative correlation between WPSH-I1 and O_3 in the PRD might be complex. The stronger WPSH and its westward extension can yield high temperature and dry weather condition in the PRD, which is conducive to elevated O_3 concentration, and vice versa. **Figure S7** shows relatively strong positive correlation between SAT and WPSH-I1, which favors growing O_3 concentrations, and negative correlation between precipitation and WPSH-I1 precipitation, which removes O_3 concentrations from air in the PRD region. From the early 2000s, Hong Kong and Guangdong provincial governments jointly lunched an O_3 pollution control program, which significantly reduced O_3 precursor emissions and its atmospheric levels in the PRD (Wu et al., 2013). It is likely that the course of O_3 reduction in the PRD coincided with the period of our modeling investigation, which interferes the statistical correlation between WPSH and O_3 in the PRD."

We agree with the Reviewer that the focus of this study should on Central and Eastern China. Considering that the WPSH is a most important summer weather and climate system in China, we briefly discussed its potential impact on weather conditions in Western and Northwestern China. In the revised first paragraph of section 2.2, we have added new statements "Although the summer WPSH determines primarily the weather and climate conditions in Eastern and Southern China, it may also influence the weather systems in Western and Northern China. For example, the westward and northward movement of the WPSH might lead to a weak high-pressure system in Northern Xinjiang extending to Central-North China, resulting in higher temperatures and lower rainfall in this region, whereas a low-pressure system could prevail in Northern and Northeastern China, enhancing precipitation in this part of China. However, given lower O_3 levels in Westernmost China (Tibet and Xinjiang), the present study did not attempt to elucidate the associations between O_3 evolution and the WPSH in this part of China but focused on Central and Eastern China where significantly higher O_3 levels were observed."

3. *Lines 38-41: Please clarify how the effect of the WPSH on regional O_3 depends on the spatial proximity to the WPSH. The WPSH position or spatial distribution is mostly controlled by the ridgeline of the WPSH with north-south shifts. why is the ridgeline index of WPSH not used in this study? The effects of the WPSH on O_3 interannual variations to the changes in air temperature, precipitation, and winds associated with the WPSH's intensity and positions. The tropospheric O_3 is*

produced with photochemical reactions of O_3 precursors under sunlight. How is the down ward solar radiation as the most important factor of meteorology? Please check the correlations.

Response: Firstly, because, as a large-scale high-pressure system, the WPSH affects significantly on its surrounding weather conditions, which, in turn, perturbs more strongly O_3 concentrations in its nearby regions. This point has been added to revised manuscript (lines 579-581).

Secondly, we did estimate correlations between seasonal O_3 time series and 4 WPSH indices, including the ridgeline index, results revealed low correlation compared with the area index and the western ridge point index. Please referred to rephrased 2^{nd} paragraph of revised section 2.2.

Thirdly, following the Reviewer's suggestion, we have added a new Fig. S9 showing the correlation between O_3 concentrations and incoming (solar) radiation flux as well as the WPSH, and corresponding discussions in main text (lines 528-538).

4. *Lines 20-21: The present study used a unique tropospheric O_3 dataset. Please clarify how is the unique in the simulated dataset? Why the WRF-Chem simulated meteorological elements are not used the climatic analysis of atmospheric circulations?*

Response: "unique" dataset means the O_3 concentration dataset covering the longest time period because available O_3 time series data in China started from 2013 only. Nevertheless, we have deleted "unique" in the revised paper.

Yes, we used both WRF simulated meteorology and NCEP reanalysis data. Considering that WRF outputs forecasted meteorological data that might be subject to errors and uncertainties from different error sources in the model, whereas NCEP reanalysis provides objectively analyzed data based on observations, we selected the NCEP reanalysis in composite analysis. We have revised section 2.3 and added this point in the rephrased section.

5. *Text 1 & Fig S1: "Considering large uncertainties of sampled ambient air quality data in the first several years, we collected monitoring data in summer 2016 to verify modeled O_3 concentrations." Some stations were built in 2015, but the time period of sampled surface O_3 concentrations is still longer than one year in China. Why did author just choose the O_3 data in 2016 summer? The modeling results seems to be not very well in 2016, it is suggested to extend the observation dataset. Besides, due to the diurnal variation of O_3, the line chart is not the best way to present the reasonability of model simulation, makers without line would be better.*

Response: Thanks for the Reviewer's suggestions. The routine O_3 sampling started in 2013 in China but there were large uncertainties in measured data due to manual intervention before 2016. In the revised paper, we have extended model evaluation from 2016 to 2016 to 2017 by adding on more year O_3 sampling data in 2017. Considering that present study focused on interannual and longer-term summer mean O_3 variation associated with the summer WPHI, we replaced hourly data by daily concentrations. Results reveal better agreement between modeled and measured concentrations, as refereed in revised SI Text 1 and Fig. S1. We still used line chart to illustrate the associations between modeled and measured O_3 time series. After replacing hourly data by daily time series, we can observe that modeled daily O_3 concentrations match well measurements in summer 2016 and 2017.

6. *Lines 152-153: "This trend possibly overwhelms interannual changes in the WPSH in the recent two decades." What does 'this trend' refer to? Growing O_3 pollution or strengthen WPSH?*

Response: It means WPSH trend. We have rephrased text.

7. *Fig S2: We cannot intuitively see the difference in the interannual trend of WPSH-I1 before and after 1999. Suggest to add the liner trend of WPSH-I1 from 1980 to 1999 in Fig. S2, to better display the reinforcement of the WPSH on a decadal scale in the recent two decades.*

Response: Thanks for the Reviewer's suggestion. We have added a trend line from 1980 to 1999 in new Fig. S2.

8. *Lines 172-174: "In the present study, we used the EOF analysis in WRF-Chem simulated gridded (20 km × 20 km) seasonal O_3 concentrations across China to extract annual O_3 change features from 1999 to 2017, respectively." I am not quite clear on what 'respectively' refers to? EOF analysis for each year or at each grid?*

Response: This was a typo error. We have deleted "respectively".

9. *Line 243: "This inland region covers several major urban agglomerations (UAs) in China". 'UAs' has appeared in the previous context.*

Response: The Reviewer is right! We have replaced urban agglomerations by UAs.

10. *Lines 271-271 "Since O3 concentrations are positively correlated with the WPSH-I1 (Figs. 3-5)" WPSH-I1 is not mentioned in Fig 5, please check the citation of figures.*

Response: Figs. 3-5 were changed to Figs. 3 and 4.

11. *Fig 3: The relative analysis of the association of WPSH with PCA2 and PCA3 are not yet described in the manuscript, please add them. Besides, third EOF pattern of O_3 is absent.*

Response: The analysis of PCA2 has been added. Since the third principal components (PCA3 and EOF3) were almost meaningless, they both are removed from the revised paper.

12. *The time period for climate mean in Fig S5 is 1999 2017, but it becomes 1980-2017 in Fig. S6. Why did author choose the different time period s for climate mean?*

Response: This was a typo error and has been corrected.

13. *Fig.4 & Fig. 8: The correlation of observed surface O_3 concentration and WPSH-I1 is also significantly negative in YRD, which is not mentioned in the analysis of Fig. 4. However, the positive contribution of meteorology was characterized by positive correlation coefficients between the WPSH-I1 and scenario 2 modeled O_3 concentrations in the eastern seaboard area in Fig. 8b. The conclusions appear to contradict each other. Please provide an explanation.*

Response: Likely we did not described clearly. **Figure 4** shows a negative correlation between modeled summer O_3 concentration and WPSH-I2 time series in the YRD under model scenario 1 but model scenario 2 yields a positive correlation (**Fig. 8b**). Since model scenario 1 took annually-altered O_3 precursor emissions into consideration, the negative correlation suggests that declining precursor emissions from 1999 to 2017 in the YRD overwhelmed the WPSH effect. After removed the effect of precursor emissions, the meteorology associated with the WPSH would help enhance O_3 concentrations in this region.

This argument has been added to revised manuscript.

14. *Lines 315-316: "We also estimated the correlations between O_3 concentrations averaged over the six UAs across China and the WPSH-I1 from 1999 to 2017 (Fig. S7). The positive correlation coefficients between the mean O_3 concentrations and the WPSH-I1 in each of the UAs are presented at the top of each column." Fig. S7 is the correlation between O_3 concentrations and PCA1, please check the citation and add the legends. What do the Y axis and X axis of the inset figure stand for? Suggest to add the correlation coefficients in each subplot, which is more intuitive to illustrate the positive correlation than scatter plots.*

Response: Given that PCA1 as the first principal component of summer O_3 time series is associated strongly with the mean summer O_3 concentrations averaged over the six UAs in China at the correlation coefficient of 0.95 ($p<0.01$) from 1999 to 2017, it seems not necessary to present the results as illustrated in Fig. S7. So we have deleted Fig. S7 in the previous version of the paper and corresponding discussion in main text (lines 315-325 of the original paper version).

15. *Lines 332-333: "Considering that summer precipitation in China is sensitive to the western ridge point of the WPSH". It is necessary to cite some references.*

Response: Following the Reviewer's suggestion, several new references are added and referred in the revised paper.