Responses to Review #2

The authors analyzed meteorological anomalies in June 2018, July 2017, September 2019 and July 2015 corresponding to severe O_3 pollution events in the NCP, YRD, PRD and SCB, respectively. The four meteorological variables (T2M, RH, SLP and GPH) which are associated with severe O_3 pollution events in these four months are then analyzed to investigate their changes in 1980-2019 and 2021-2100, and their changes are predicted to lead to more severe O_3 pollution in the future. The topic is interesting, and the conclusion is important for better control of O_3 pollution. However, there are still issues that need to be addressed before the paper can be considered for publication.

We thank the reviewer for the helpful comments. Below, please see our point-by-point response (in blue) to the specific comments and suggestions and the changes that have been made to the manuscript, in an effort to take into account all the comments raised here.

Comments:

Lines 28-31: The readers may assume the conclusion is based on the most severe O3 pollution months over these regions, but they are June 2018, July 2017, September 2019 and July 2015 for the NCP, YRD, PRD and SCB, respectively, that is, one month per region. It is unclear whether one month can represent the meteorological conditions of severe O_3 pollution events sufficiently.

Response:

Thank you for the comment. Many previous studies have analyzed the synoptic patters of regional O_3 pollution in China and found several meteorological conditions could lead to O_3 pollution. In this study, we focus on the most extreme O_3 pollution cases in many regions of China rather than the high O_3 pollution cases in a particular region. The similar scientific question and method have been applied in aerosol pollution studies (e.g., Li et al., 2018; Yang et al., 2021). We admit that other meteorological conditions besides the ones we analyzed in the manuscript can also cause regional O_3 pollution. However, these high pollution cases are much more complicated and are suit for further analysis in the individual regions.

We have now added a statement in the discussion as "In addition, this study focuses on the most extreme O_3 pollution in several polluted areas of China. However, many other meteorological conditions can also cause O_3 pollution, although they may not be as extreme as the cases analyzed in this study, which requires comprehensive analysis for individual regions in future studies." We have also revised the description in the abstract to "During the most severe O_3 polluted months, the chemical production of O_3 is enhanced under the hot and dry conditions over the North China Plain (NCP) in June 2018 and Yangtze River Delta (YRD) in July 2017, while the regional transport is the main reason causing the severe O_3 pollution over Sichuan Basin (SCB) July 2015 and Pearl River Delta (PRD) in September 2019."

Furthermore, the severe O_3 pollution events in the SCB are interpreted as regional transport from Northern China (as shown in Figure 5b). Consequently, meteorological variables SLP and GPH were selected to describe severe O_3 pollution in the SCB. However, it is hard to believe regional transport from Northern China could be the dominant factor for severe O_3 pollution events in the SCB which has strong local anthropogenic emissions and is surrounded by mountains. In lines 160-162, the authors indicated "In the top three O_3 polluted months in Chengdu, only in July 2015 the higher concentrations than the long-term averages can be captured by the simulations with fixed emissions", and it is the reason why July 2015 was selected to represent the SCB in the analysis. However, does this imply inaccuracy in the model simulations to interpret severe O_3 pollution events in the SCB? Are SLP and GPH suitable meteorological variables to describe severe O3 pollution events in the SCB in the past and the future?

Response:

In this study , we focus on the meteorological characteristics of severe ozone pollution events in different regions in China. For the GEOS-Chem simulations, the precursor emissions of O_3 are fixed to minimize the influence of interannual variations in emissions. Therefore, when comparing to the observations, the differences between the model and observations are partly attributed to the emission changes. But the possible model bias can also contribute to the difference.

We have now added a paragraph in the last section to discuss the polluted month in SCB, as "There are some limitations and uncertainties in this work that can be further addressed in future studies. For example, the model only captures the high O_3 concentrations in July 2015 in Chengdu among its top three polluted months. It is probably because the emissions are kept at 2017 levels during the simulations. The high O_3 anomalies in July 2016 and July 2018 are more likely influenced by the interannual changes in local precursor emissions in the background of country-level increases in O_3 concentration in recent years. However, we also can not rule out the possible inaccuracy in the model simulations to interpret severe O_3 pollution events in the SCB, which deserves further investigation with multi-model simulations."

To date, several studies have pointed out the importance of regional transport as the cause of O_3 pollution in SCB (Qiao et al., 2019; Shen et al., 2022; Shu et al., 2023; Yang et al., 2020). Shen et al. (2022) examined the source-receptor relationships of O_3 in China and showed that O_3 received by SCB from other areas in central and eastern China could reach 26.7%. Shu et al. (2023) investigated the mechanism of O_3 pollution at different altitudes in the western part of SCB and found that the O_3 concentration at the top of the mountain due to the regional transport. Yang et al. (2020) explored the formation and evolution mechanism of O_3 pollution in SCB by using the WRF-CMAQ model simulations and also reported that the high ozone concentration in Chengdu during one O_3 pollution case was mainly due to mixing and regional transport of O_3 precursors through vertical mixing and horizontal advection from upwind areas.

Therefore, the regional transport can lead to O_3 pollution in SCB driven by anomalous atmospheric circulation pattern, which is sometimes characterized by SLP and GPH.

Lines 152-155: Why is Chengdu not mentioned in this sentence?

Response:

Added as "The top three highest frequencies of O_3 pollution days in Chengdu are in July 2016, July 2015 and July 2018 (16, 15 and 15 days per month, respectively)."

Figure 2: How are these anomalies calculated?

Response:

We have revised the figure caption to "**Figure 2.** Spatial distribution of monthly O_3 concentration anomalies (part per billion, ppb) in June 2018 (a), July 2017 (b), July 2016 (c), July 2015 (d), July 2018 (e) and September 2019 (f) relative to 40-year (1980–2019) monthly average for June (a), July (b, c, d, e) and September (f), simulated in the GEOS-Chem model. The green boxes mark NCP (a), YRD (b), SCB (c, d, e) and PRD (f)."

Figure 3a: Is it 850 hPa (figure title) or 1000 hPa (caption) wind anomalies? The same question for Figures 4-6.

Response:

We apology for the typo. It should be 850 hPa. Revised now.

Section 3.2: The discussion in this section is simple. It could be better to provide a quantitative comparison of the impacts of each meteorological variable on the high O_3.

Response:

The impact of each meteorological variable on O_3 pollution has been fully documented in the introduction. For the quantitative analysis, we used the integrated process rate (IPR) analysis from GEOS-Chem simulations to examine the possible physical and chemical mechanisms for the O_3 pollution and discussed the meteorological characteristics related to the changes in O_3 mass. Although each meteorological variable could exert different impact on O_3 pollution, it may not be appropriate to isolate the relative role of each meteorological variable, since many meteorological variables have internal relations and change simultaneously.

Figure 8c-d: These two panels are associated with the conclusion "In SCB and PRD, the occurrence of atmospheric circulation patterns similar to those during the polluted months increased, together with the more frequent hot and dry conditions, contributing to the increases in severe O_3 pollution in SCB and PRD during 1980–2019". First, it is suggested to add uncertainty estimates particularly for July 2015 (SCB) to determine whether there are significant trends in the meteorological anomalies. Moreover, is it possible to have quantitative estimations for the possible contributions from meteorological changes to O_3 changes in 1980-2019 to confirm the importance of meteorological changes?

Response:

For the historical changes in SLP and GPH, we did not draw a conclusion that there are clear trends of historical SLP and GPH that are similar to those in the polluted months, but only the changes in frequencies between two time period (1980–1999 vs. 2000–2019) based on meteorological reanalysis. The analysis of frequency trend requires much longer time data than 40-year during 1980–2019. Any uncertainty here can only come from the uncertainties in the reanalysis data itself, which is not the focus of this study.

The historical changes in the meteorological patterns causing severe O_3 pollution are in accordance with the elevated O_3 levels in China in the recent decade. However, the quantitative analysis of meteorological impacts needs full consideration of factors leading to O_3 pollution, including changes in anthropogenic and natural emissions of its precursors, O_3 chemical regime, other meteorological factors conducive to O_3 pollution, and stratosphere-troposphere exchange. We have added this discussion in the last paragraph of the manuscript.

Section 7: It could be helpful to provide a comparison of the impacts of meteorological changes in 1980-2019 and 2021-2100 to extend the discussion in this section.

Response:

Thank you for the suggestion. We have now added the discussion as "Unlike the historical changes in the meteorological conditions that caused the severe O_3 pollution through chemical production and regional transport, future variations in meteorological conditions conducive to the severe O_3 pollution are more related to the global warming process that enhances the O_3 production in China."

Reference

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