Responses to Reviewers' comments

To the esteemed Editor and Reviewers,

We would like to thank the reviewers for the time and efforts in reviewing our manuscript. We have revised the manuscript according to the reviewers' detailed comments, which we sincerely hope the correction will meet with the high publishing standard of the journal. Please find the point-to-point responses to the reviewers' comments as follows:

Reviewers' comments are in black.

Author's responses are in blue color.

Changes in the manuscript are in red color.

Sincerely,

Weihua Chen

On behalf of the authors

Response to Reviewer #2:

Referee #2 comment:

The study analyzed the spatial and temporal characteristics of nocturnal ozone increase (NOI) events over the Pearl River Delta (PRD) region in southern China. A long-term (2006-2019) record of the NOI events were identified based on surface ozone measurements and meteorology reanalysis, and interpreted with vertical lidar measurements and a regional model simulation. The results showed that low-level jets (LLJs) and convective storms (Conv) were the main drivers of the NOI events. Underlying processes were also analyzed using sample NOI events.

Overall, I think this is a well conducted study, offering quite comprehensive information on the NOI events (trend, seasonal variation, spatial distribution, triggering process) over the PRD region. In particular, the study emphasized the important role of vertical transport, combined with daytime ozone levels for the occurrence of NOI.

The presentation of the manuscript is also clear and in general concise. I recommend publish on ACP after the following comments been addressed.

Response:

We thank the reviewer for the positive comments. We have incorporated all your constructive comments and suggestions in the revised manuscript.

Specific comments:

1. Page 5, Section 2.1

For the definition of NOI, how did you define "remaining for at least 1h" as hourly ozone measurements were used. For example, in Figure 9a, there was a second ozone peak at 0300 am. Would you define this peak as a NOI event?

Response:

Thanks for pointing out this critical issue.

The definition of "remaining for at least 1h" means a decrease in O_3 of less than 10 μg m^{-3} at the next hour.

The second O_3 peak at 03:00 will not be recorded as an NOI event because we record the frequency of NOI events on a unit of day and do not focus on how many NOI events have occurred on a single night.

We have clarified the definition of NOI in Lines 155-161:

'For our analysis, we define a nocturnal O_3 increase (NOI) event as O_3 concentrations peaked at night (from 21:00 LT to 06:00 LT the next day), with an increase in levels of at least 10 μg m^{-3} compared to the previous hour and a decrease of less than 10 μg m^{-3} in the next hour. The corresponding nighttime peak concentration of O_3 is referred to as the nocturnal O_3 peak (NOP) (Zhu et al., 2020). In this study, based on the above observed hourly O_3 data at the 16 air quality monitoring sites, NOI events are identified at each site, yet only one NOI event is recorded per night, regardless of how many NOI events occur in a single night.'

2. Page 6, Section 2.2

The definitions of LLJ and Conv events need some further clarification. In the analysis below, there are LLJs, Conv, and LLJs&Conv events. How did you define LLJs&Conv? Were they also accounted in the LLJs or Conv events?

Response:

Thanks for your suggestion. In our study, NOI events are classified into 4 categories: caused by LLJs only, caused by Conv only, caused by LLJ and Conv at the same time, and caused by other factors. LLJs&Conv in the original manuscript means an NOI event caused by LLJs and Conv at the same time. We have replaced "LLJs&Conv" with "LLJs+Conv" to keep consistency throughout the revised manuscript. We have clarified it in Lines 186-188:

'In this study, an NOI event at each air quality site was classified into four categories: caused by LLJs only, caused by Conv only, caused by LLJs and Conv (LLJs+Conv) at the same time, and caused by other factors.'

3. The title of Section 2.2 "simulated meteorological data"

Suggest change it to "Meteorology reanalysis data", to avoid confusion with the WRF simulated meteorology.

Response:

Modified as suggested.

4. Section 2.4

The dry deposition process (DDEP) was included in the process analysis, however, when using Figure

10, DDEP was not shown there even for the surface ozone concentration. This seemed to be unclear and unexplained. Can you please check and clarify it?

Response:

We apologized for the missing calculation of DDEP in the original manuscript. We have replotted Figure 10 as follows:

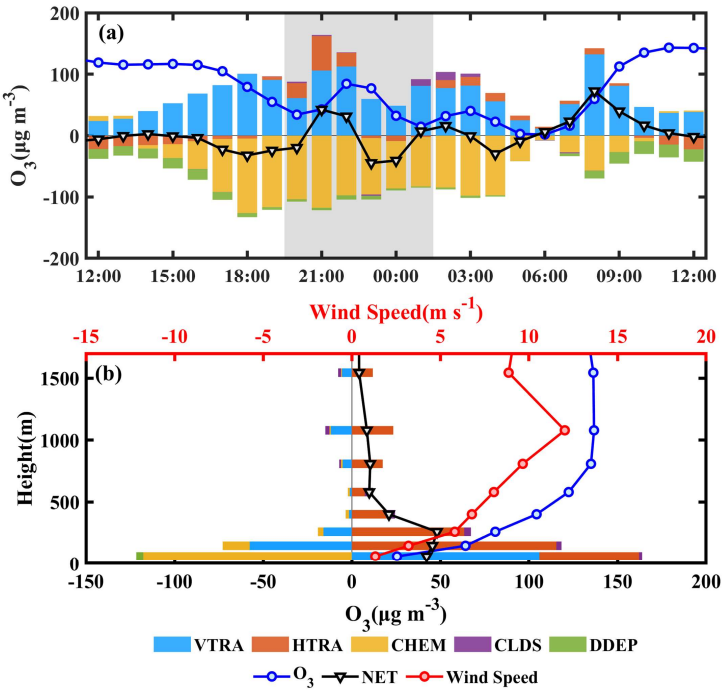

Figure 10. Contribution of individual processes to (a) hourly O_3 concentration near the surface during September 13-14, 2017 and (b) vertical O_3 concentration at 21:00 on September 13, 2017. VTRA: vertical transport, the net effect of vertical advection and diffusion; HTRA: horizontal transport, the net effect of horizontal advection and diffusion; CHEM: gas-phase chemistry; CLDS: cloud processes; DDEP: dry deposition; NET: the net change in O_3 due to all atmospheric processes.

5. Line 438-440, and in Abstract.

How about the 16% of NOI events attributed to LLJs&Conv? Were these events triggered by LLJs or Conv?

Response:

16% of NOI events were caused by LLJs and Conv at the same time. We have modified the description in Lines 19-20 and Lines 511-512:

'Low-level jets (LLJs) are the main meteorological processes triggering NOI events, explaining on average 61% of NOI events.' (Lines 19-20)

'LLJs are the dominant factors causing NOI events (61%), followed by the combination of LLJs and Conv (LLJs+Conv) with a value of 16%.' (Lines 511-512)

6. Page 14, Section 3.5

In Figure 7, there were three stations in the southern part that showed very high NOI frequencies, while the LLJs frequencies were low there. Can you explain and discuss this feature?

Response:

Thanks for pointing out this important issue. Highest frequency of NOI events for the three sites located in the southern part of the PRD regions were also affected by non-LLJs (=Conv+(LLJs+Conv)+Other) because the contributions of LLJs and non-LLJs to the NOI events were comparable at these three sites, while the contributions of LLJs (60-70%) were higher than that of non-LLJs at the rest of sites (Table S5). We have provided more descriptions in Lines 383-388:

'At the three sites located in the southern part of the PRD regions (TJ, TW, and TC), the frequency of NOI events was the highest while the frequency of LLJs was not. This is because these three sites were also affected by non-LLJs (=Conv+(LLJs+Conv)+Other) processes with comparable contributions of LLJs and non-LLJs to the NOI events. And the contributions of LLJs (60-70%) were higher than those of non-LLJs at the rest of sites (Table S5).'

7. Section 3.5, Figure 8

It is not clear that why analyzing the difference between urban and rural areas could elaborate the effect of meteorological process. Based on their locations (Figure 7a), the difference between urban and rural areas may not reflect their urban vs. rural land cover, but their different spatial locations. Please clarify.

Response:

We agree with the reviewer that analyzing the difference between urban and rural areas cannot elaborate the effect of meteorological. We have deleted this paragraph and maintained spatial analysis in the revised manuscript.

Technical comments:

8. Line 300, "Hance" should be "Hence"

Response:

Modified as suggested.

9. Line 308, figure caption, “blue” should be “orange”

Response:

Modified as suggested.

10. Line 425, “improve the next day chemical budget”. The word “improve” is misleading here.

Response:

We have replaced “improve” with “impact” in the revised manuscript.

Reference:

Zhu, X. W., Ma, Z. Q., Li, Z. M., Wu, J., Guo, H., Yin, X. M., Ma, X. H., and Qiao, L.: Impacts of meteorological conditions on nocturnal surface ozone enhancement during the summertime in Beijing, Atmos. Environ., 225, 117368, https://doi.org/10.1016/j.atmosenv.2020.117368, 2020.