

## Response to Review #1

Review of “2013-2019 increases of surface ozone pollution in China: anthropogenic and meteorological influences” by Ke Li, Daniel J. Jacob, Lu Shen, Xiao Lu, Isabelle De Smedt and Hong Liao, submitted to Atmospheric Chemistry and Physics.

Summary: Based on statistical analysis of recent surface measurements of ozone in China and meteorological conditions from a modern reanalysis product, the authors quantify the role of meteorology versus emissions on the positive ozone trends in Chinese megacities. Despite regulations targeting ozone pollution, ozone has continued to increase over the past decade.

While the results are interesting, they seem preliminary. Section 3 is a list of “Figure X shows” and I encourage the authors to add depth to their research and analysis and more fully develop their narrative. There are five figures, which are all multi-paneled, and only three pages of “Results and discussion”; this unequal balance of figure to text highlights the need for further exploration into the information contained in each figure. In addition, there is a supplemental figure and supplemental table which I found added to the analysis and I encourage the authors to include these in the main text.

This manuscript is within the scope for Atmospheric Chemistry and Dynamics; however, I suggest the authors expand the discussion of the results before I recommend it for publication.

We appreciate the reviewer’s constructive and thorough comments/suggestions. We have moved the supplementary figure and table to the main text. We also have detailed the description of MLR model and foehn wind effect. Figures have been also revised following your suggestions, thanks! Please find below our point-by-point response in blue.

### Major comments:

Pg 2 Ln 15: The authors discuss VOCs as additional industrial sources but there can be natural sources of VOCs from plants. Have the authors considered the natural sources of VOCs in this analysis? There’s no discussion of natural VOC emissions on Page 6 or 7.

Thanks. We have added the discussion in P4L28-30: “The effect of biogenic VOCs on ozone trends depends on meteorological and land cover drivers. Meteorological drivers, in particular temperature, would be accounted for in the MLR model. The effect of land cover changes is expected to be small over the 7-year time horizon of our analysis (Fu and Tai, 2014).”

Pg2 Ln 27: The authors should include the MEE website here in the body of the text and in the Data Availability section at the end of the manuscript.  
Added.

Pg 4 Ln 15, 20: These trend values are provided in Figure 2. What is novel about Table S1 is it highlights that a significance test was performed. In Line 20, the authors quote “significantly enhanced” without a reference to a statistical test. The authors should describe this in the Data and Methods Section at the bottom of Page 3 and I would encourage the authors to include this table in the main text as it is referenced on Page 4 Line 21 to support a critical result.

Thanks! Now it (as Table 1) has been added in the main text. For statistical test, we have added in P4L24-25: “with the statistical significance of the anthropogenic trend determined by Student’s *t*-test”

Pg4 Ln 30: The authors reference a supplemental figure which I would argue should be in the main text as it highlights not only the change in maritime inflow which impacts the Shandong Peninsula, but it looks like the YRD and Northeast China as well. The authors should discuss how the meteorological conditions mitigate ozone pollution over western China (does that include SCB?) and northeast China.

Thanks! Now it (as Figure 3) has been added in the main text. We also have added the discussion on the decreasing ozone trends in P6L8-9: “Temperature decreased over northeastern China (Figure 3).”

Pg4 Lines 22,23 and Page 5 Ln15: The authors could go into more detail on not only the primary meteorological predictor variables, and also include the breakdown for all megacities and regions discussed. Only NCP and PRD’s principal predictors are given.

We have added the plots of leading meteorological variables in Supplementary Figures S1-3, which are also cited in the main text.

**Figure comments:**

Pg 4 Line 7: It would make it easier on the reader if the rectangles in 2019 Figure 1 top row were included in 2019 Figure 1 middle row since the text is discussing both mean MDA8 and the max MDA8 by region.

Added.

Pg 14 Figure 1:

While the figure caption includes the latitude and longitude for the four megacity clusters, the latitude and longitude ticks are not labelled. Can [some of] the ticks be labelled, or at least include in the caption what are the intervals of the major and minor ticks and some reference point?

Would the discussion of the ozone max and mean trends benefit from the max PM<sub>2.5</sub> being included in Figure 1? Has the maximum PM<sub>2.5</sub> decreased the same as the mean (Pg4 Lines 4-5). If that is the case, could state that and not show it.

We have revised Figure 1, and the maximum PM<sub>2.5</sub> trends are also added to Figure 1. We have added in P5L9-10 about the decrease of maximum PM<sub>2.5</sub>: “Maximum PM<sub>2.5</sub> concentrations experienced a similar decrease trend.”

Page 15 Figure 2: Can the rectangles for the megacity clusters be added to Figure 2 or at least Figure 2a? I did my best to draw them on so I could follow the text referring to the trends in the four regions. Again, it would be helpful to have some of the latitude and longitude tick marks labelled and/or the intervals of the major and minor ticks and some reference point defined in the figure caption.

Done.

Page 15 Line 10: Could add a reference to the Table S1 at the end of the caption.

Added.

Pg 5 Line 8: This sentence references the Table in Figure 3. The left figure and right table should be labelled as (a) and (b) to make referencing in the text clearer. Also, to save on white space, I would encourage the authors to include the table as an inset in Figure 3 or as a separate table.

The ozone trend has been already given in the main text and We have removed the right table now.

Pg 17 Line 7-9: The definition of the Foehn index and foehn-favorable conditions should be in Section 2 or in the text of Section 3; I suggest it is removed from the figure caption.

Thanks! We have included the definition of foehn index in P7L-10 in Section 3. We would like to still include this in the Figure caption to make the Figure self-explanatory.

Pg 17 Line 9-10: “The frequency of foehn wind under hot days increased by 85% over the period” is a result and should be in the main text and not in the figure caption. Can the authors go into more detail about this trend? Was it mainly driven by 2018 and 2019?

Yes. We have moved this into the main text in P7L11-13: “The frequency of foehn conditions under hot days in June increased by 85% over the 2013–2019 period (driven mainly by the increased frequency in 2018–2019), and ozone increase under foehn conditions is 1.2 ppb a<sup>-1</sup> larger than under no-foehn conditions.”

#### **Minor and technical comments:**

Pg1Ln19: The June-July temperatures over the NCP are higher than what? Other regions of China? Other months?

Higher than previous years. We have changed “higher” to “rising” for clarification.

Pg2Ln18: Can the authors describe how meteorological conditions may affect emissions? Are they referring to natural emissions from plants which do vary based on meteorological conditions, or do they mean anthropogenic emissions such as through energy consumption?

We intended to say “natural emissions”, which are much more meteorologically dependent than anthropogenic emissions. We have added “natural” in P2L19.

Pg 3 Line 1: No mention of NO<sub>2</sub> surface observations but these are referenced in Figure 5.

Added.

Pg 3 Line 12: There was a version change in the TROPOMI NO<sub>2</sub> data in March 2019 (<https://sentinel.esa.int/documents/247904/2474726/Sentinel-5P-Level-2-Product-UserManual-Nitrogen-Dioxide>). I am concerned this change could add a bias when comparing Summer 2018 (v1.2.0) vs Summer 2019 (v1.3.0).

Thank you for pointing this out. Now we have removed the results for TROPOMI NO<sub>2</sub> changes.

Pg 4 Line 2: A paragraph of preamble providing an overview of the results section would be good, to help the reader see that there are three subsections within Section 3.

Great suggestion.

We have added in this in the beginning of Section 3: “We first present the general 2013–2019 summer ozone trends in China and their statistically decomposed meteorological and anthropogenic contributions. Ozone trends over the major megacity clusters in China are highlighted. We go on to more specifically attribute the meteorological and anthropogenic drivers of recent ozone trends over the North China Plain, where the ozone increase is the highest.”

Pg 4 Line 10: Do the authors have a hypothesis as to why the summer maximum MDA8 ozone values in YRD, PRD, and SCB were comparable to the NCP but not the means?

We have added the explanation in P5L16-19: “These three megacity clusters are subject to similar ozone pollution episodes under stagnant conditions as the NCP (Wang et al., 2017), but they are more frequently ventilated by the summer monsoon bringing cleaner tropical air and precipitation hence the lower mean ozone.”

Pg 4 Ln 14: Can the authors provide latitude and longitude regions for Shandong Peninsula and Northeast China. Line 28, the authors refer to ‘northeastern’ China. Is this different than Northeast China?

We now use “northeastern” instead of “Northeast” throughout the text for consistency. We intended to focus on the four major megacities clusters that are also the pollution control regions targeted by the Chinese government.

Shandong Peninsula typically refers to the east part of Shandong province; Northeast China typically includes Helongjiang, Jilin, and Liaoning provinces. We have added this information in the main text (P5L22).

Pg 5 Lines 2-3: It looks to me that the anthropogenic trend is more uniformly positive in Fig 2c than Figs 2a,b except for in the Shandong Peninsula and maybe the PRD and YRD regions. Can the authors confirm?

Yes, you are right. The meteorological role varies regionally. We have revised the text in P6L11-12: “This anthropogenic trend is more uniformly positive at a national scale...”

Pg 5 Line 4: Why might the PRD experience a decrease? Is that because of the change in monsoon winds? Make connections between the figures and discussion where possible.

Yes, due to weakened monsoonal winds. We have added the explanation in P6L15-16: “The ozone increase in PRD is mainly meteorologically driven due to reduced monsoonal winds (**Figure 3**).”

Pg 5 Line 16: While the June (August) temperatures clearly show increasing (decreasing) trends over the 2013-2019 period, the temperature pattern in July looks almost neutral if averaged over this period and not “a lesser increase”. This phrase is awkward.

In fact, the temperature trend in July ( $0.22\text{ }^{\circ}\text{C a}^{-1}$ ) is comparable with trend in August ( $-0.18\text{ }^{\circ}\text{C a}^{-1}$ ), while both of them are much lower than trend in June ( $0.42\text{ }^{\circ}\text{C a}^{-1}$ ). The high temperature in 2018–2019 is the reason for an increasing temperature trend in July. We have added the temperature trends in P6L29 and P7L1.

Pg 5 Line 21: The reference following foehn winds gives me the impression that this paper is the first to define foehn winds. However, a foehn wind is the warming of air through adiabatic descent on the lee side of a mountain, much like a Chinook Wind on the lee side of the Rocky Mountains, so the reference is likely more appropriate at the end of the sentence. The authors should describe the foehn wind in meteorological terms, whereby air which is forced to rise over the mountains, loses much of its water vapor to condensation on the windward side, and subsequently warms dry adiabatically as it descends on the lee side.

Great suggestion.

We have added the introduction in P7L5-7: “Foehn wind conditions featuring warm and dry air subsiding from the mountains that are to the north and west of the NCP (Chen and Lu, 2016) also lead to high ozone pollution in the NCP.”

Pg 5 Line 22,23: The phrase “winds blow from the mountains to the north and west” is confusing. Either the mountains are to the north and west of NCP and the wind blows from the mountains to the NCP, or the wind blows to the north and west, from the mountains to NCP. Possibly this level of detail could be included in the meteorological definition for the foehn wind which would simplify this sentence, or the use of latitude and longitude for the mountain range versus the region defined for the NCP.

Revised. Please see our response to last comment.

Pg 6 Line 3: Are the MEE sites in the NCP average all full time series or are any partial records during the period? It would be good to state that like you did for Figure 2.

We have revised in P7L17: “...all MEE sites in the NCP and including sites with partial records.”

Pg 6 Line 6: Can the authors quantify the “much less month-to-month variability” (e.g., possibly through the standard deviation)?

Thanks! We have added this information in P7L21-22: “The standard deviation decreases from 8.8 ppb to 5.3 ppb after removal of meteorological influence.”

Pg 6 Line 9,15: Provide a reference that NO<sub>2</sub> is a proxy for NO<sub>x</sub> emissions. Could instead include this idea and a reference in the introduction (Pg 2).

Added. We also revised the text in P2L26-28: “bring in satellite and ground-based observations to relate the most recent ozone trends to those of VOC (Shen et al., 2019b) and NO<sub>x</sub> emissions (Zheng et al., 2018; Shah et al., 2020).”

Pg 6 Line 14-15: The authors quote decreases in PM<sub>2.5</sub> and NO<sub>x</sub> emissions for 2017-2019 but the base year or period is not provided.

Base year is 2017. We have revised in P8L2: “Relative to 2017, we find for 2019 a 15% ...”

Pg 6 Line 28: add “and” between “Province and Northeast”  
Done.

Pg 7 Line 5-6: How do these values compare to the Chinese and US National Ambient Air Quality Standards? Good to put this in perspective of the health standards.

We have added in P8L23-24: “In comparison, the Chinese air quality standard for annual maximum MDA8 ozone is 82 ppb.”

Pg 7 Line 9: Change “warning” to “warming”  
Changed.