Response to referee comments on “Spatial distribution and temporal trend of ozone pollution in China observed with the OMI satellite instrument, 2005–2017”

We thank the referees for their careful reading of the manuscript and the valuable comments. This document is organized as follows: the Referee’s comments are in *italic*, our responses are in plain text, and all the revisions in the manuscript are shown in blue. The line numbers in this document refer to the updated manuscript.

Referee 3

This paper explored the capability of OMI ozone columns to represent the surface O3. I feel the satellite data is over-interpreted based on the evidence provided in the paper. However, I do believe it will be big news if substantial improvements are made to prove that the conclusion is solid.

Response. We thank the reviewer for raising so many good points, which have significantly improved our work. Now we have a new Figure 4 showing that OMI 850-400 retrievals have limited skill in predicting the daily ozone variability in the north and we only predict the trends of ozone pollution in southern China (south of 34°N). We have new in-situ observations to validate the trends inferred from the OMI, which are shown in Figure 6. And we have revised the title.

New title. Ability of the OMI satellite instrument to observe surface ozone pollution in China: application to 2005-2017 ozone trends

General comments:

1. The sensitivity of OMI O3 to the lower troposphere is very low. I feel that is the reason why no quantitative comparison to surface observations has so far been done. I’m wondering is there any improvements that have been made to make the quantitative comparison robust? Why does not the quantitative comparison work for other regions, but work for China?

Response. We now explain this better in the Introduction.

P2L23. However, no quantitative comparison of the satellite data to surface observations has so far been done. Surface ozone network data are available in the US and Europe but levels are generally too low to enable statistically meaningful validation. Ozone levels in China are much higher (Lu et al., 2018). The high density of the MEE network, combined with vertical profile information from ozonesondes and aircraft, provides a unique opportunity for evaluating quantitatively the ability of OMI to observe ozone pollution.

2. *The robustness of the residual. How large is the temporal and spatial variations of the background? Is it likely that such variations bring significant uncertainties to the subtraction?*

Response. Thanks for making this good point. We have tested different approaches to correct the background and the results are consistent with what have presented in the paper. In the text, we make it simple by saying this.

P4L1. We examined different spatial and temporal averaging domains for the North Pacific background and found little effect on the residual.

The uncertainty related to the background correction can be found in these two figures.

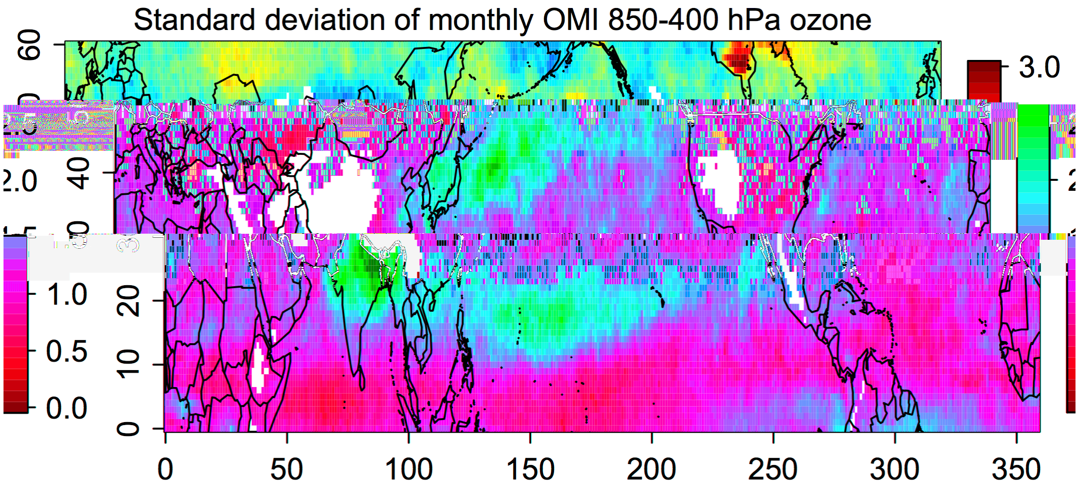

Figure SX. Standard deviation of monthly OMI 850-400 hPa ozone during 2005-2017 summers.

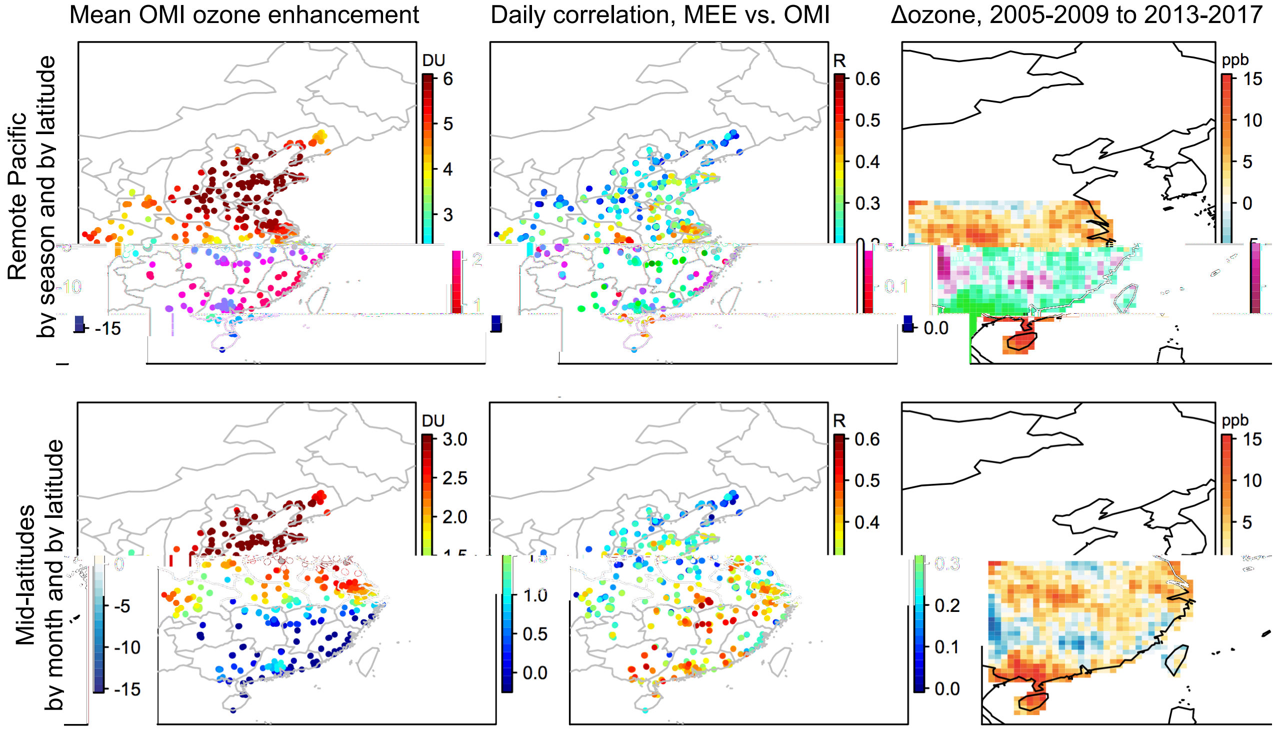

Figure SX. The mean ozone enhancement (left panel), daily correlation of OMI and MEE ozone (mid panel), and the OMI inferred changes of mean ozone concentrations from 2005-2009 to 2013-2017 using different approaches correcting the OMI drift. In the top panel, we subtract the monthly mean Pacific background (150°E-150°W) for the corresponding latitude and season. In the bottom panel, we subtract the monthly mean mid-latitude ozone for the corresponding latitude and month.

3. *The correlation between MEE and OMI. The correlation seems to be related with the dependence of O3 on latitude. I suggest additional analysis here to prove that is not the case.*

Response. We are not sure if the reviewer is referring to Figure 1f here. In Figure 1f, the correlation is higher in the south and lower in the north. This is because in the northern China, OMI 850-400 hPa ozone has lower sensitivity in the boundary layer, more likely to be influenced by the upper tropospheric ozone variability and stratosphere-troposphere exchange. We have added new discussion in the text.

P6 L27. We find that the low correlation of OMI with boundary layer ozone in the northern ozonesonde data is due not only to the low DOFS but also to a large variability of ozone in the upper troposphere. Figure 4 (left panel) shows the standard deviation of daily OMI 400-200 hPa ozone during 2005-2017 summers, indicating that upper tropospheric ozone has much higher variability in the north (> 34°N) than in the south. This is related to the location of the jet stream and more active stratospheric influence (Hayashida et al., 2015). Figure 4 (right panel) displays the vertical profiles of ozone standard deviations for the five ozonesonde sites. For the two sites north of 34°N, the ozone variability becomes very large above 8 km. Since the OMI 850-400 hPa retrieval also contains information from above 400 hPa, this upper tropospheric variability causes a large amount of noise that masks the signal from boundary layer variability. For the three sites south of 34°N, the ozone variability in the boundary layer is much higher than in the free troposphere and the upper tropospheric ozone variability still remains low even above 8 km. In the rest of this paper we focus our attention on ozone episodes and the long-term trends in southern China (south of 34°N).

If the reviewer refers to Figure 1d, we now make it clear that we have corrected the background that is dependent on latitudes.

P3 L23. To remove this gradient and also any long-term uniform drift in the data, we subtract the monthly mean Pacific background (150°E-150°W) for the corresponding latitude and month

P4 L22. After subtracting the North Pacific background for the corresponding latitude in month, we obtain the OMI ozone enhancements shown in Figure 1d.

P4 L23. The spatial correlation coefficient between the OMI ozone enhancements and the MEE surface network is R = 0.73 over eastern China. The correlation is driven in part by the latitudinal gradient but also by the enhancements in the large megacity clusters identified as rectangles in Figure 1b. Thus the correlation coefficient is R = 0.55 for the 26-34°N latitude band including YRD, SCB, and Wuhan.

Specific comments:

1. "We exclude outliers with over 35 Dobson Units (DU) at 850- 400 hPa (>99th percentile in eastern China) and exclude July 2011 when the retrievals are anomalously high." Please give the reference to the exclusion. Otherwise, please quantify the influence of the exclusion.

Response. Thanks for pointing this out. We delete this because we don't use the July 2011 data and not excluding the extremely high data has little effect on our result.

2. "We see that high-ozone episodes in the 950-850 hPa sonde data are systematically associated with high OMI values, though the converse does not always hold." Additional explanation for the reason is expected.

Response. Thanks. Now we say

P6L4. We see that high-ozone episodes in the 950-850 hPa sonde data are systematically associated with high OMI values, though the converse does not always hold because free tropospheric enhancements affecting OMI can also occur.