Response to Reviewer I

General Comments:

- This manuscript studied the impact of meteorological changes and emission reductions on $PM_{2.5}$ pollution in the Pearl River Delta (PRD) during the cold seasons from 2015 to 2017. The authors aimed to explain why $PM_{2.5}$ levels in the PRD remained high despite of significant emission reductions in PRD and its upwind regions in East China. By applying the regional models, they found that transport contributions to $PM_{2.5}$ levels rose from 70% in 2015 to 78% in 2017, while local emissions declined. And they concluded that the meteorology change was the dominant driver of the multiannual variations of $PM_{2.5}$ during the studied period. And the meteorological change was likely driven by large scale climate variability, namely the transition from a strong El Niño in 2015 to a weak/moderate La Niña in 2017. This study also pointed out that the meteorological impact should be taken into consideration when the emission control policies were assessed.
- The manuscript is well organized and written clearly, the description is precise, and the discussion is fruitful. I recommend publishing it after minor revision. Below are my comments referring to lines (L), equations (Eqs.) and figures (Fig.).

Response:

We appreciate the valuable comments and suggestions. Our responses to specific comments are provided in blue and the corresponding revisions are highlighted in red. Please note that the line numbers (indicated by "Lx") are those in the revised manuscript with the author's changes.

Specific comments:

L160: spinning -> spanning

Response:

Thank you for noticing this spelling mistake. We corrected it as suggested.

L149: (1) Maybe it is better to specify the names of nine cities here when this concept is first mentioned. (2) It seems that not all the nine cities are shown in Fig. 1.

Response:

(1) We provided the names of nine cities in L163-164 of the original manuscript. Since the concept of "nine cities" is firstly mentioned here, we moved the above information to L150-151:

… this study used $PM_{2.5}$ monitoring data in the nine cities of the PRD (including Guangzhou, Shenzhen, Jiangmen, Zhuhai, Foshan, Dongguan, Zhaoqing, Huizhou and Zhongshan; Fig. 1), …

(2) The names of cities have been added in the new Fig. 1:

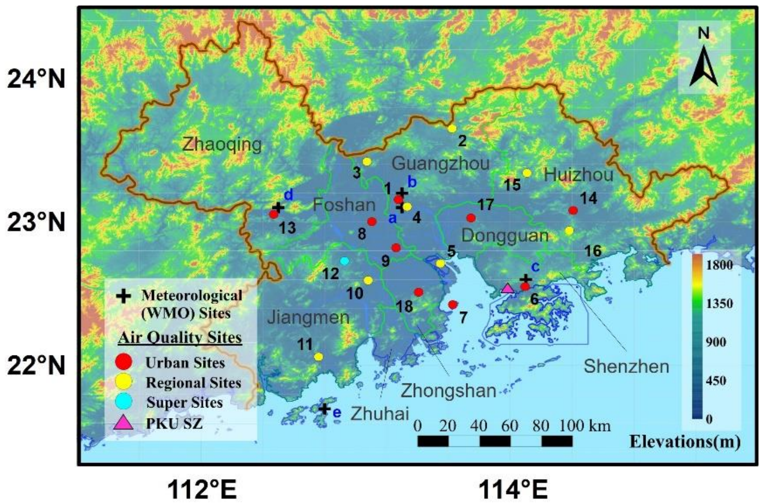


Fig. 1: (1) The x tick labels and y tick labels need to show the unit, e.g., 112 °E. (2) The orange line is not introduced in the caption.

Response:

(1) The axis labels have been revised, as suggested, in the new Fig. 1.

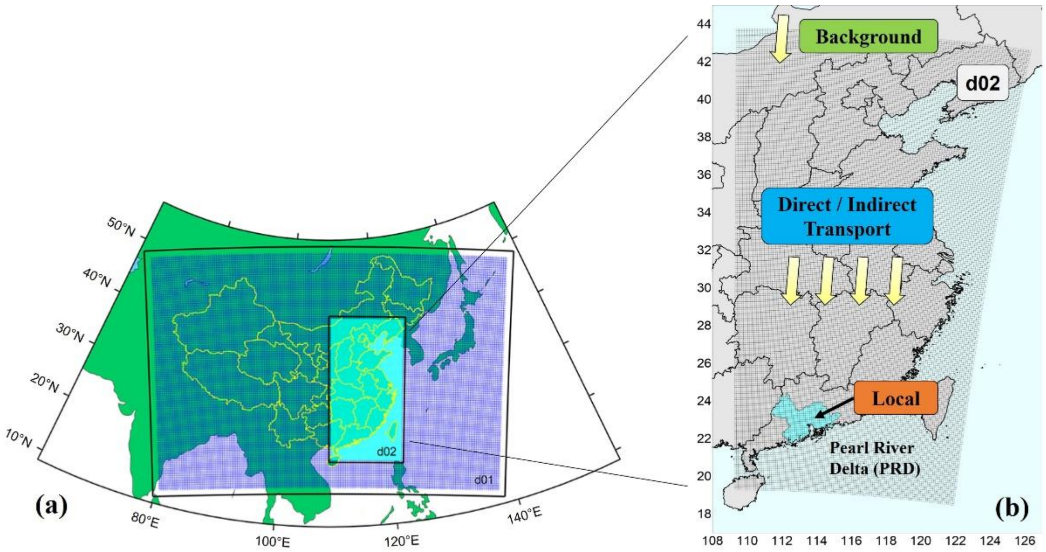
(2) We added the information of the orange line in the caption, in L161-162:

… The orange line indicates the boundary of the PRD region.

Fig. 2: (1) The latitude and longitude labels are too small. (2) "The black boxes are the simulation domains for WRF, while the nested areas indicate the simulation domains for CMAQ.": Does it mean that d01, d02, and the domain larger than d01 are all simulated by WRF? And CMAQ only simulates d01 and d02? Please specify it clearly.

Response:

(1) The axis labels have been revised in the new Fig. 2:



(2) Both WRF and CMAQ simulations are performed within d01 and d02, as introduced in the main text. However, the WRF domains are slightly bigger than the corresponding CMAQ domains, and that's why we used black boxes and nested areas to separately indicate the domains of two models. To avoid confusion, we've revised the sentence, as in L201-202:

The black boxes indicate the WRF simulation domains, which are slightly larger than the corresponding CMAQ domains, as represented by nested areas. Both WRF and CMAQ are applied to d01 and d02.

L190: Oct and Dec are selected in the simulations, but in L159, the cold season is defined as the period from Oct to Jan. Will this affect the simulation results?

Response:

We agree that focusing on two months in the simulations could potentially introduce some differences compared to the results for the full four-month cold season. However, the overall impact is likely minor.

$PM_{2.5}$ transport to the PRD region during Oct-Jan is mainly driven by the East Asian winter monsoon, which maintains stable northeasterly wind patterns throughout this period (Ren et al., 2022). Although its intensity varies in different months, the general transport pathways and source contributions of $PM_{2.5}$ in adjacent cold-season months remain similar.

We selected Oct. and Dec. to represent typical autumn and winter conditions, respectively, and used the combined results of these two representative months to approximate the overall cold-season state. The large amount of simulation hours (~1500 h per cold season) ensures statistically sufficient sampling to cover the cold-season variability in our analysis. More importantly, it restricts the simulation period, allowing for more efficient use of computational time and storage while still enabling robust investigation of $PM_{2.5}$ sources and their inter-annual variations.

Eqs. 5 - 10: Why the contribution of S_Emis_O,15/16 is not calculated by C_L15O16M15 - C_Base15? And similar questions for S_Meteo,15/16, S_Emis_O,16/17, and S_Emis_L,16/17?

Response:

Thank you for this comment. To clarify, in theory, the contribution of $S_{Emis\_O,15/16}$ could be estimated by directly comparing the simulation results of the L15O16M15 and Base15 scenarios. However, we adopted the current design of simulation scenarios because it captures the accumulated effects of changes in local emissions, outer emissions and meteorology, while ensuring that the sum of the three individual contributions between two adjacent years equals the net change in concentrations or source contributions. This approach of designing simulation scenarios has been widely applied in similar studies (Jiang et al., 2022).

Fig. 4: The x tick labels and y tick labels need to show the unit, e.g., 110 °E.

Response:

The axis labels have been revised in the new Fig. 4:

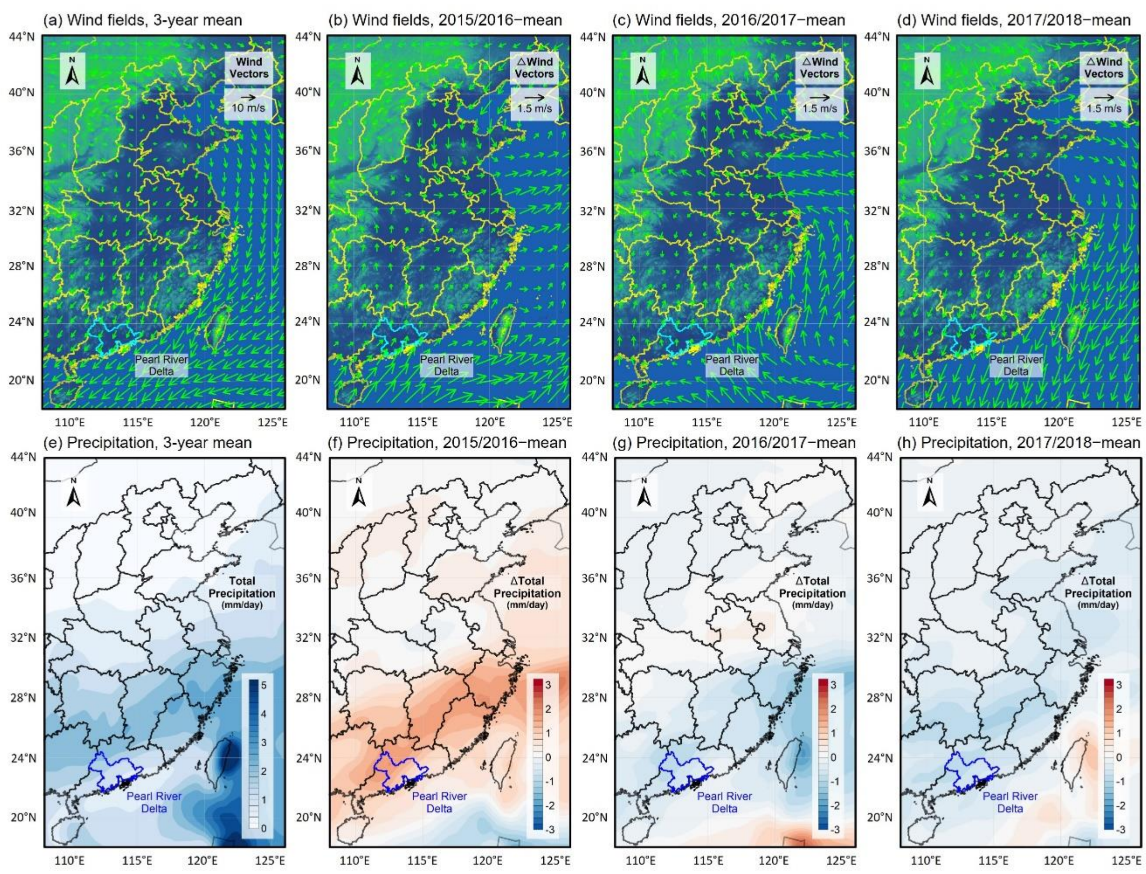
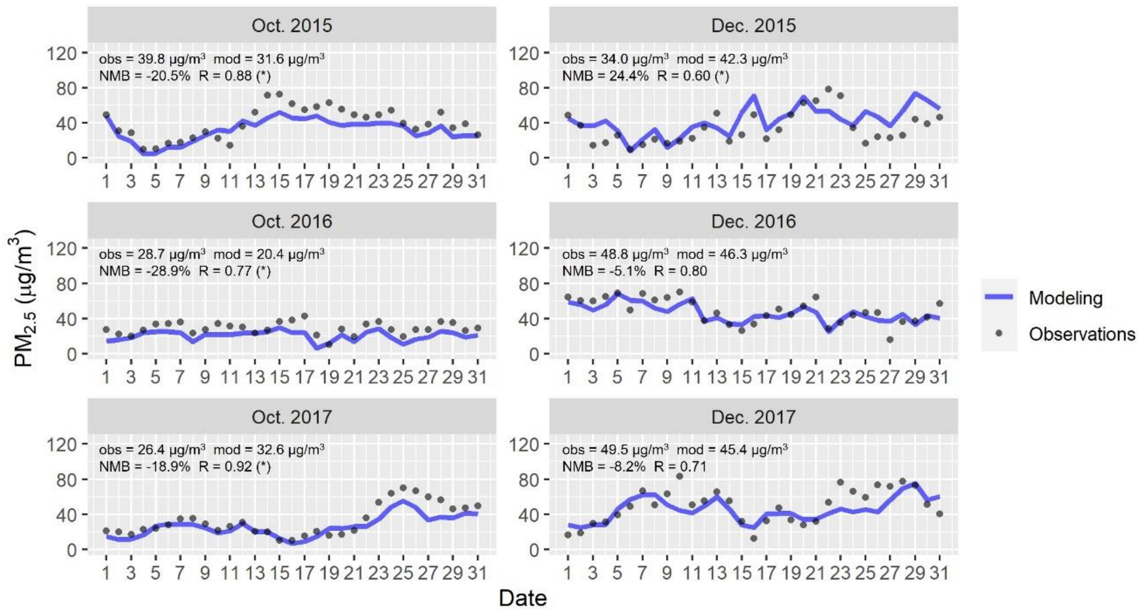


Fig. 5: The legend of "Observations" is point instead of point+line.

Response:

The legend of "Observations" has been corrected in the new Fig. 5:



L412: What does 'population-weighted mean' represent?

Response:

The population-weighted mean concentration of pollutants is a widely used metric in air quality assessment studies, especially those focusing on human exposure (e.g., Li et al., 2017). In comparison to the normally used area-weighted concentration, this metric assigns greater weight to regions with higher populations, thereby providing a more representative estimate of the health effect of air pollutants. We have added more details on this metric in the Method section, in L253-259:

The simulated population-weighted pollutant concentration is used for further source apportionment calculation and analysis. As it better indicates the effect of air pollutants on human health, this metric is widely used in air quality assessment studies (e.g., Li et al., 2017c). The population-weighted concentration ($f_{pop-weighted}$) is calculated as follows:

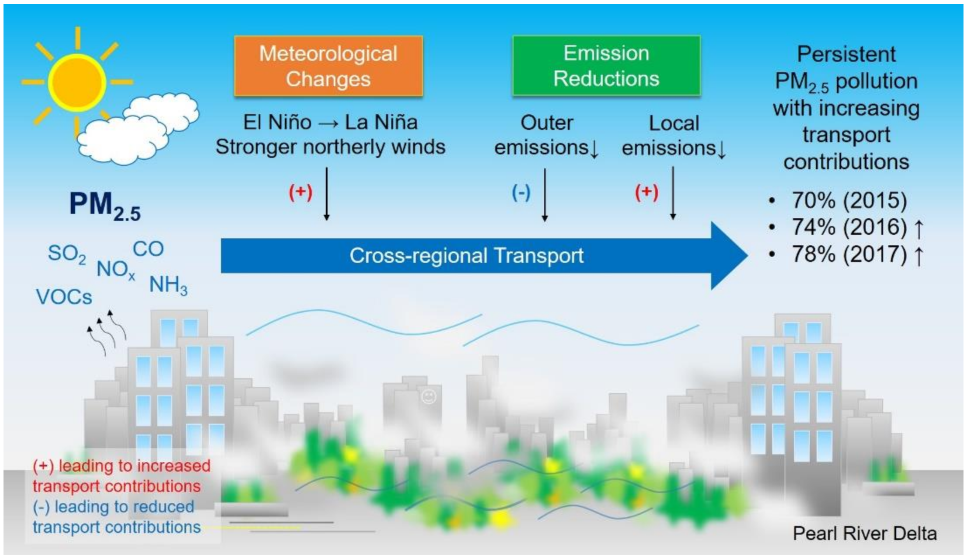
$$f_{pop-weighted} = \frac{\sum_{i=1}^{N} f_i p_i A_i}{\sum_{i=1}^{N} p_i A_i} \quad (1)$$

where f_i is the simulated pollutant concentration in the grid cell i; p_i is the population density within the grid cell i; A_i indicates the area of the administrative PRD region within the grid cell i; N is the total number of grid cells within the simulation domain. Gridded population density data for the year 2015 were obtained from the GPWv4 dataset (last access: 14 September 2017; Doxsey-Whitfield et al., 2015) and applied in the above calculation.

Fig. Graphic Abstract: Why the decrease of local emissions is marked with "Enhanced"?

Response:

It means the decrease of local emissions contributed to the increase in transport contributions, or enhanced the effect of cross-regional transport. To make it clear, we've revised the Graphic Abstract, as follows:



References

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