**Response to Reviewers**

**No.:** ACP-2025-10

**Title:** Anthropogenic and Natural Causes for the Interannual Variation of $PM_{2.5}$ in East Asia During Summer Monsoon Periods From 2008 to 2018

**Anonymous referee #1:**

This study presents the results of simulations performed with the RegCM-Chem-YIBs Model over the period 2008-2018. The study focuses on $PM_{2.5}$ concentrations over China and explores the drivers of change in simulated concentrations before and after the implementation of a Clean Air Action Plan in 2013. This is an interesting study and certainly within the scope of ACP.

**Response:** We thank Referee #1 for his/her valuable comments, which have greatly improved our manuscript. We have attempted to make a revision addressing each of the points mentioned in his/her review. Please note that the line numbers given below refer to the clean version of the manuscript.

1. Whilst the paper presents an interesting set of experiments, it would be strengthened further if the authors could comment on the extent to which this modelling framework captures the temporal and spatial variability of observed $PM_{2.5}$ across China during the specific time period concerned. There are many studies that have analysed and reported measured $PM_{2.5}$ concentrations, several of which are already cited in your Introduction, and could be used to offer a comparison. Others include:

Silver et al., 2018, Environ. Res. Lett. 13 114012

Ma et al, 2019, Atmos. Chem. Phys., 19, 6861–6877

Kong et al., 2021, Earth Syst. Sci. Data, 13, 529–570

Silver et al., 2025, Environment International, 197, 109318

**Response**: Thank you for your valuable suggestions. We have added a comparative analysis with existing studies on $PM_{2.5}$ concentration changes in China in Section 3.1 "$PM_{2.5}$ variation". The results show that the simulated $PM_{2.5}$ trends from 2008 to 2018 in this study are highly consistent with most previous findings, further validating the reliability of our simulation results.

Changes in manuscript:

3.1 $PM_{2.5}$ variation

(L259–270): "Table S1 shows that the mean $PM_{2.5}$ trend over China during the PreG (2009-2013) and PostG (2014-2018) periods was −1.84 μg/m$^3$/yr and −2.90 μg/m$^3$/yr, respectively. These values are consistent with the findings of Silver et al. (2025), who reported a $PM_{2.5}$ trend of −2.47 μg/m$^3$/yr for 2014–2017 in China based on ground-based observations. Similarly, Lin et al. (2018) reported $PM_{2.5}$ trends of −0.65 and −2.30 μg/m$^3$/yr for 2006–2010 and 2011–2015 in China, respectively. Using satellite remote sensing data, Ma et al. (2019) found declines of 1.03 and 4.27

μg/m$^3$/yr for 2010-2013 and 2013-2017 in China, respectively. The high-resolution Chinese air quality reanalysis (CAQRA), developed by Kong et al. (2021) using data assimilation techniques, indicated a more pronounced decline of −5.80 μg/m$^3$/yr for $PM_{2.5}$ from 2013 to 2018 in China. In addition, Silver et al. (2018), based on multi-source data, reported a trend of −3.40 μg/m$^3$/yr for 2015–2017 in China. Therefore, our simulation accurately captures the observed $PM_{2.5}$ trends over China from 2008 to 2018, providing a robust foundation for subsequent attribution analyses."

**Table S1.** Interannual trends of near-surface $PM_{2.5}$ concentrations (μg/m$^3$/year) during the PreG period (2009–2013) and PostG period (2014–2018) relative to 2008 over the NCP, FWP, YRD, PRD, and SCB regions.

| Year | NCP | FWP | YRD | PRD | SCB | Average |
|---|---|---|---|---|---|---|
| PreG | -0.69 | -2.84 | -0.71 | -1.55 | -3.44 | -1.84 |
| PostG | -4.94 | -2.49 | -2.63 | -0.56 | -3.86 | -2.90 |

**References**


Kong, L., Tang, X., Zhu, J., Wang, Z., Li, J., Wu, H., Wu, Q., Chen, H., Zhu, L., Wang, W., Liu, B., Wang, Q., Chen, D., Pan, Y., Song, T., Li, F., Zheng, H., Jia, G., Lu, M., Wu, L., and Carmichael, G. R.: A 6-year-long (2013-2018) high-resolution air quality reanalysis dataset in China based on the assimilation of surface observations from CNEMC, Earth System Science Data, 13, 529-570, 10.5194/essd-13-529-2021, 2021.

Lin, C. Q., Liu, G., Lau, A. K. H., Li, Y., Li, C. C., Fung, J. C. H., and Lao, X. Q.: High-resolution satellite remote sensing of provincial PM<sub>2.5</sub> trends in China from 2001 to 2015, Atmos Environ, 180, 110-116, 10.1016/j.atmosenv.2018.02.045, 2018.

Ma, Z., Liu, R., Liu, Y., and Bi, J.: Effects of air pollution control policies on PM<sub>2.5</sub> pollution improvement in China from 2005 to 2017: a satellite-based perspective, Atmospheric Chemistry and Physics, 19, 6861-6877, 10.5194/acp-19-6861-2019, 2019.

Silver, B., Reddington, C. L., Arnold, S. R., and Spracklen, D. V.: Substantial changes in air pollution across China during 2015-2017, Environmental Research Letters, 13, 10.1088/1748-9326/aae718, 2018.

Silver, B., Reddington, C. L., Chen, Y., and Arnold, S. R.: A decade of China's air quality monitoring data suggests health impacts are no longer declining, Environment International, 197, 10.1016/j.envint.2025.109318, 2025.


Specific comments:

2. Line 11: This sentence doesn't quite make sense - remove word "changes".
**Response**: Thanks. We have removed the word "changes" in the revised version.

Changes in manuscript:

Abstract

(L11–12): "There was a significant difference in near-surface $PM_{2.5}$ across China after the implementation of the Clean Air Action Plan in 2013."

3. Line 16: You haven't defined PreG or PostG yet so it's a bit confusing to mention these here. You could either define them or describe the time periods without referring to them by these names.

**Response**: Thanks. We have revised the expressions and clearly defined PreG and PostG in the updated manuscript.

Changes in manuscript:

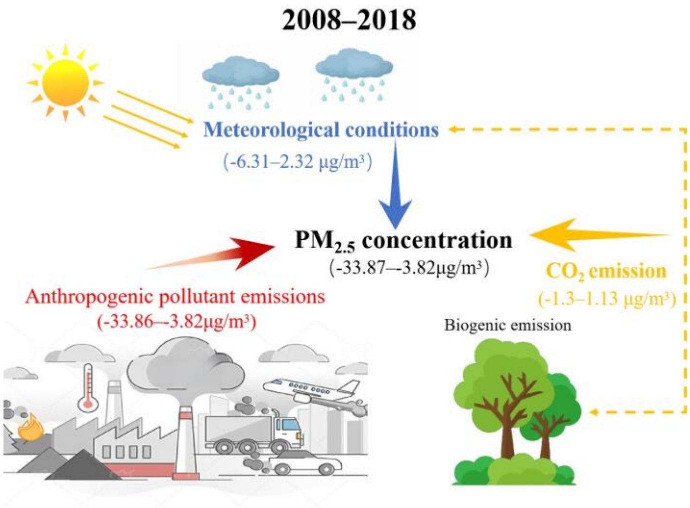
Abstract

(L15–18): "Compared to 2008, $PM_{2.5}$ showed little variation during the PreG phase (2009–2013). However, during the PostG phase (2014–2018), a substantial decline in $PM_{2.5}$ was simulated, particularly in the North China Plain (-36.76 μg/m³) and the Sichuan Basin (-33.96 μg/m³)."

4. Graphical abstract: At the moment the diagram is slightly confusing and it ideally needs to be entirely self-explanatory since the graphical abstracts do not come with a caption. It's also not clear what "~" is being used to represent here: are these ranges?

**Response**: Thanks for pointing that out. We have replaced the tilde (~) with a hyphen (–) to indicate ranges. Additionally, the Graphical abstract has been optimized to enhance clarity and make it more self-explanatory.

Changes in manuscript:




5. Lines 31-38: You refer to $PM_{2.5}$ as if it is a single entity, whereas in reality it's an aggregation of part of the aerosol size distribution, and could be comprised of many different components (this is most relevant to your description of the impact of $PM_{2.5}$ on climate) - I suggest rewording this paragraph to reflect this.

**Response**: Thanks for pointing out this issue. We have added a more detailed description of $PM_{2.5}$ in the revised manuscript.

Changes in manuscript:

Introduction

(L32–36): "$PM_{2.5}$ refers to fine particulate matter with an aerodynamic diameter less than or equal to 2.5 micrometers (Chen et al., 2018). Its sources include industrial emissions, vehicular exhaust, biomass burning, and secondary formation from atmospheric gases (Wu et al., 2020). Major chemical components of $PM_{2.5}$ include sulfates, nitrates, ammonium salts, organic carbon, elemental carbon, and heavy metals (Van Donkelaar et al., 2019; Li et al., 2017a)."

**References**

Chen, G. B., Li, S. S., Knibbs, L. D., Hamm, N. A. S., Cao, W., Li, T. T., Guo, J. P., Ren, H. Y., Abramson, M. J., and Guo, Y. M.: A machine learning method to estimate PM<sub>2.5</sub> concentrations across China with remote sensing, meteorological and land use information, Sci Total Environ, 636, 52-60, 10.1016/j.scitotenv.2018.04.251, 2018.

Li, G. H., Bei, N. F., Cao, J. J., Huang, R. J., Wu, J. R., Feng, T., Wang, Y. C., Liu, S. X., Zhang, Q., Tie, X. X., and Molina, L. T.: A possible pathway for rapid growth of sulfate during haze days in China, Atmospheric Chemistry and Physics, 17, 3301-3316, 10.5194/acp-17-3301-2017, 2017a.

van Donkelaar, A., Martin, R. V., Li, C., and Burnett, R. T.: Regional Estimates of Chemical Composition of Fine Particulate Matter Using a Combined Geoscience-Statistical Method with Information from Satellites, Models, and Monitors, Environmental Science & Technology, 53, 2595-2611, 10.1021/acs.est.8b06392, 2019.

Wu, K., Yang, X. Y., Chen, D., Gu, S., Lu, Y. Q., Jiang, Q., Wang, K., Ou, Y. H., Qian, Y., Shao, P., and Lu, S. H.: Estimation of biogenic VOC emissions and their corresponding impact on ozone and secondary organic aerosol formation in China, Atmospheric Research, 231, 10.1016/j.atmosres.2019.104656, 2020.

6. Lines 42-46: Reword this slightly to clarify whether these are all annual average values, as written it sounds as though some of them could be the maximum value recorded.

**Response**: Thank you for pointing out this issue. We have slightly revised the wording in the manuscript to clarify that these values represent averages.

Changes in manuscript:

Introduction

(L48–52): "From 2000 to 2008, the national average $PM_{2.5}$ concentration in China was 49.4 ± 14.2 $\mu g/m^3$. In eastern China, the average concentration was 55.4 ± 16.1 $\mu g/m^3$, while the Beijing-Tianjin-Hebei region experienced average levels as high as 62.1 ± 22.5 $\mu g/m^3$. The Yangtze River Delta saw an average concentration of 63.0 ± 11.1 $\mu g/m^3$, the Pearl River Delta recorded an average of 52.4 ± 5.8 $\mu g/m^3$, and the Sichuan Basin averaged 61.6 ± 13.4 $\mu g/m^3$.

7. Lines 74-81: clarify here that as well as affecting photosynthesis, elevated $CO_2$ concentrations can directly inhibit the emission of isoprene. Temperature is mentioned in the previous section in terms of its impact on chemical reactions, but changes in temperature will also drive changes to BVOC emissions (and the partitioning of BVOC oxidation products from the gas to particle phase) so this could be mentioned in the Introduction too.

**Response:** Thanks. We have added some discussions on this aspect.

Changes in manuscript:

Introduction

(L68–74): "In addition, moderate increases in temperature can significantly enhance the emissions of biogenic volatile organic compounds (BVOCs) by stimulating the activity of the synthase enzyme. However, when temperatures exceed the physiological tolerance threshold of plants, decreased enzyme activity or metabolic disruption may suppress emissions(Lindwall et al., 2016; Kleist et al., 2012). Therefore, temperature changes can influence atmospheric $PM_{2.5}$ concentrations by modulating the emissions of BVOCs."

(L89–94): "It is worth noting that elevated $CO_2$ concentrations may also directly inhibit BVOCs emissions by reducing the activity of BVOCs synthase enzymes(Heald et al., 2009; Pegoraro et al., 2004). Therefore, the impact of increased $CO_2$ on vegetation BVOCs emissions can be either positive or negative, depending primarily on the relative strength of the inhibitory effect from enzyme suppression versus the stimulatory effect from enhanced photosynthesis(Sun et al., 2012)."

**References**

Heald, C. L., Wilkinson, M. J., Monson, R. K., Alo, C. A., Wang, G. L., and Guenther, A.: Response of isoprene emission to ambient CO2 changes and implications for global budgets, Global Change Biology, 15, 1127-1140, 10.1111/j.1365-2486.2008.01802.x, 2009.

Kleist, E., Mentel, T. F., Andres, S., Bohne, A., Folkers, A., Kiendler-Scharr, A., Rudich, Y., Springer, M., Tillmann, R., and Wildt, J.: Irreversible impacts of heat on the emissions of monoterpenes, sesquiterpenes, phenolic BVOC and green leaf volatiles from several tree species, Biogeosciences, 9, 5111-5123, 10.5194/bg-9-5111-2012, 2012

Lindwall, F., Schollert, M., Michelsen, A., Blok, D., and Rinnan, R.: Fourfold higher tundra volatile emissions due to arctic summer warming, Journal of Geophysical Research-Biogeosciences, 121, 895-902, 10.1002/2015jg003295, 2016.

Pegoraro, E., Rey, A., Bobich, E. G., Barron-Gafford, G., Grieve, K. A., Malhi, Y., and Murthy, R.: Effect of elevated CO<sub>2</sub> concentration and vapour pressure deficit on isoprene emission from leaves of <i>Populus</i> <i>deltoides</i> during drought, Functional Plant Biology, 31, 1137-1147, 10.1071/fp04142, 2004.

Sun, Z. H., Niinemets, Ü., Hüve, K., Noe, S. M., Rasulov, B., Copolovici, L., and Vislap, V.: Enhanced isoprene emission capacity and altered light responsiveness in aspen grown under elevated atmospheric CO2 concentration, Global Change Biology, 18, 3423-3440, 10.1111/j.1365-2486.2012.02789.x, 2012.

8. Lines 82-85: specify here that you are referring to China as the same may not be true for other regions.

**Response**: Thanks. We have now specified that the region in question is China.

Changes in manuscript:

Introduction

(L97–99): "Numerous studies have used statistical models and numerical simulations to investigate the impacts of meteorological conditions and anthropogenic pollution emissions on $PM_{2.5}$ concentration changes in China."

9. Line 168: can you be more specific than "more favourable meteorological conditions"? What are the main differences in meteorology in this region that lead to lower $PM_{2.5}$ concentrations?

**Response**: Thanks. We have included an explanation of "more favourable meteorological conditions" in the revised manuscript.

Changes in manuscript:

3.1 $PM_{2.5}$ variation

(L226–230): "In contrast, regions in western China (Yunnan, Gansu, Xinjiang) exhibit lower $PM_{2.5}$ levels due to limited industrial activity, lower population density, and more favorable meteorological conditions (Low water vapor content, lower temperatures, and weak solar radiation are unfavorable for the formation of secondary aerosols such as sulfates, nitrates, and organic aerosols) (Wei et al., 2021; Xue et al., 2020).

**References**

Wei, J., Li, Z. Q., Lyapustin, A., Sun, L., Peng, Y. R., Xue, W. H., Su, T. N., and Cribb, M.: Reconstructing 1-km-resolution high-quality PM2.5 data records from 2000 to 2018 in China: spatiotemporal variations and policy implications, Remote Sens Environ, 252, ARTN 11213610.1016/j.rse.2020.112136, 2021.

Xue, W. H., Zhang, J., Zhong, C., Ji, D. Y., and Huang, W.: Satellite-derived spatiotemporal PM2.5 concentrations and variations from 2006 to 2017 in China, Sci Total Environ, 712, 10.1016/j.scitotenv.2019.134577, 2020

10. Line 105: Model Description - it would be useful to include some details around how the model calculates BVOC emissions (since this process is important to your results) - specifically, how are these emissions affected by $CO_2$ concentration; I don't think this is covered in your previous paper (Ma et al 2023a).

**Response**: Thanks. We have added some discussions on this aspect.

Changes in manuscript:

2.1 Model description

(L129–135): “The YIBs model employs a leaf-level BVOC emission scheme based on vegetation photosynthesis. Unlike the traditional MEGAN (Model of Emissions of Gases and Aerosols from Nature) model, this approach incorporates the influence of plant photosynthesis on BVOC emissions, making it more representative of actual plant physiological processes. In this scheme, leaf-level BVOC emission rates depend on the photosynthetic rate, leaf surface temperature, and intracellular $CO_2$ concentration (Yue and Unger, 2015; Lei et al., 2020; Yue et al., 2015).

(L141–148): “In the RegCM-Chem-YIBs model, changes in $CO_2$ concentrations affect $PM_{2.5}$ primarily via two mechanisms: first, $CO_2$-induced radiative forcing alters the atmospheric radiation balance, leading to shifts in temperature, precipitation, and boundary-layer structure that modulate $PM_{2.5}$ formation, transport, and removal(Li and Mölders, 2008; Matthews, 2007); And second, through the YIBs module, changes in $CO_2$ concentration modulate photosynthetic activity and stomatal behavior, altering BVOCs emissions that undergo atmospheric photochemical oxidation to form secondary organic aerosols, a significant fraction of $PM_{2.5}$ (Kergoat et al., 2002; Kellomaki and Wang, 1998).”

**References**

Kellomaki, S. and Wang, K. Y.: Growth, respiration and nitrogen content in needles of Scots pine exposed to elevated ozone and carbon dioxide in the field, Environmental pollution (Barking, Essex : 1987), 101, 263-274, 10.1016/s0269-7491(98)00036-0, 1998.

Kergoat, L., Lafont, S., Douville, H., Berthelot, B., Dedieu, G., Planton, S., and Royer, J. F.: Impact of doubled CO<sub>2</sub> on global-scale leaf area index and evapotranspiration:: Conflicting stomatal conductance and LAI responses -: art. no. 4808, Journal of Geophysical Research-Atmospheres, 107, 10.1029/2001jd001245, 2002.

Lei, Y. D., Yue, X., Liao, H., Gong, C., and Zhang, L.: Implementation of Yale Interactive terrestrial Biosphere model v1.0 into GEOS-Chem v12.0.0: a tool for biosphere-chemistry interactions, Geoscientific Model Development, 13, 1137-1153, 10.5194/gmd-13-1137-2020, 2020.

Li, Z. and Mölders, N.: Interaction of impacts of doubling CO<sub>2</sub> and changing regional land-cover on evaporation, precipitation, and runoff at global and regional scales, International Journal of Climatology, 28, 1653-1679, 10.1002/joc.1666, 2008.

Matthews, H. D.: Implications of CO<sub>2</sub> fertilization for future climate change in a coupled climate-carbon model, Global Change Biology, 13, 1068-1078, 10.1111/j.1365-2486.2007.01343.x, 2007.

Yue, X. and Unger, N.: The Yale Interactive terrestrial Biosphere model version 1.0: description, evaluation and implementation into NASA GISS ModelE2, Geoscientific Model Development, 8, 2399-2417, 10.5194/gmd-8-2399-2015,

2015.
Yue, X., Unger, N., and Zheng, Y.: Distinguishing the drivers of trends in land carbon fluxes and plant volatile emissions over the past 3 decades, Atmospheric Chemistry and Physics, 15, 11931-11948, 10.5194/acp-15-11931-2015, 2015.

11. Figure 1: it would be better if the words in each box weren't split across lines, as some of them currently are. This could be solved by making some of the boxes slightly larger.

**Response**: Thank you for your valuable suggestion. We have enlarged the boxes to prevent word wrapping.

Changes in manuscript:

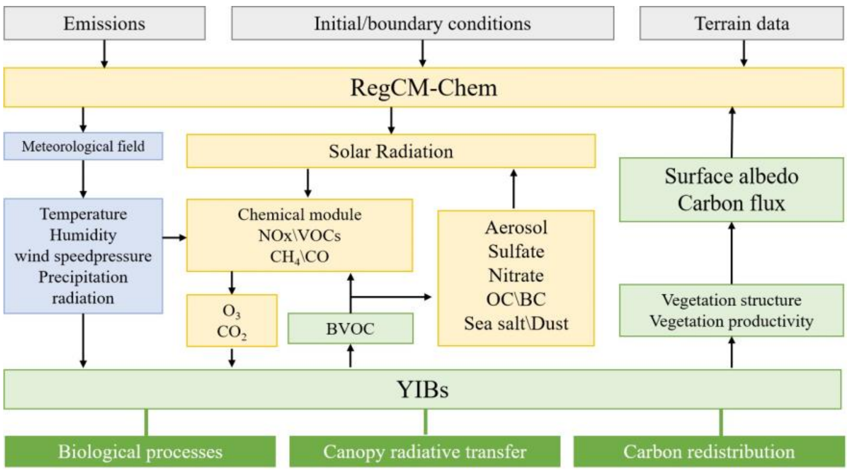



**Figure 1.** Framework of the RegCM-Chem-YIBs Model.

12. Figure 3: Correct the units on the legend within the figure.

**Response:** Thanks. We have corrected the units on the legend within the figure.

Changes in manuscript:

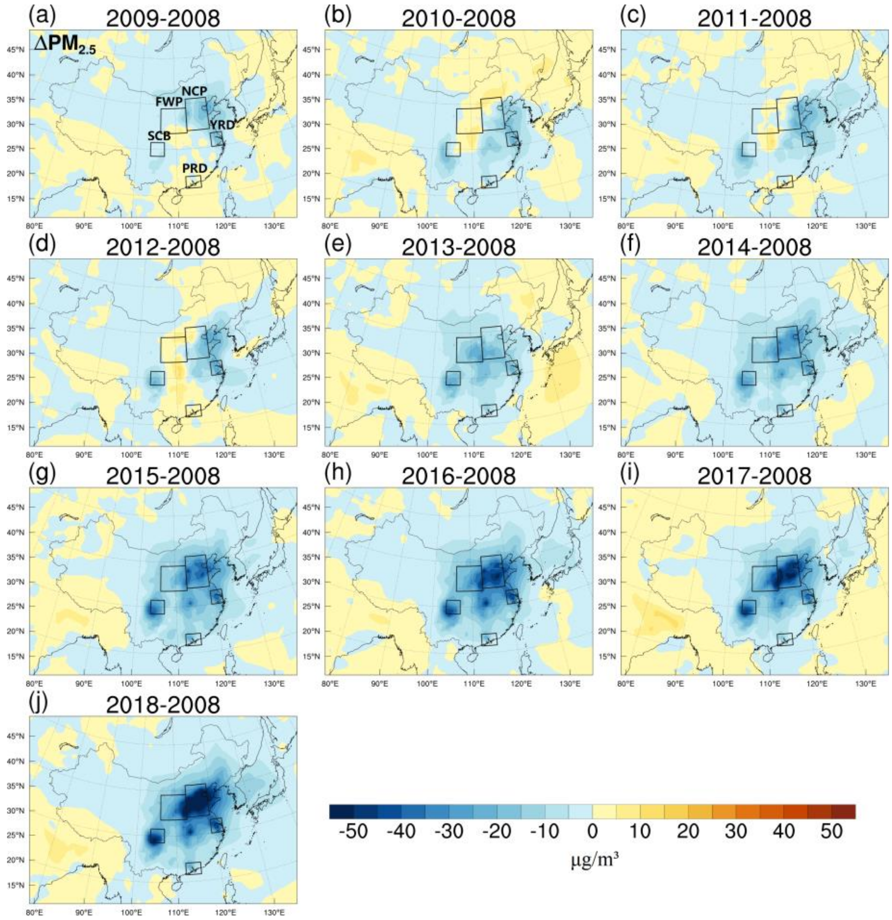



**Figure 3.** Changes in near-surface $PM_{2.5}$ concentrations (μg/m³) during the EASM period from 2009 (a) to 2018 (j) relative to 2008 in East Asia ($SIM_{Base}$ - $SIM_{2008}$).

13. Line 207: In Section 3.2 it's not completely clear which time periods the values you report are referring to, i.e., for the PreG period, are these the changes between 2008 and 2013? Or is it the average of 2008-2013 minus 2008. I think this is confused by Figure 4 where it's not clear which time period the central and right-hand columns refer to. Some Figure captions specify May to August but add this to the others that don't.

**Response**: Thanks. Sorry for the mistake. "PreG-2008" represents the average of 2008-2013 minus 2008. We have revised the corresponding figure titles accordingly and replaced "May–August" with "EASM" throughout.

Changes in manuscript:

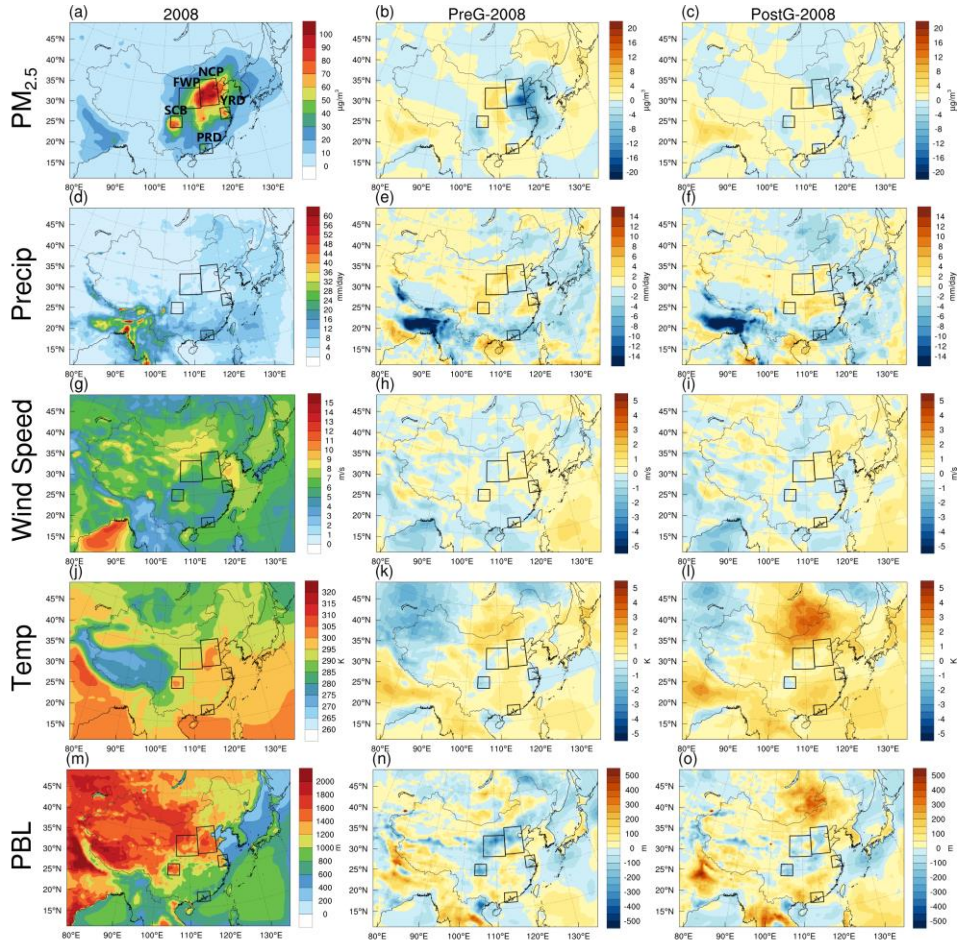



**Figure 4**. The $PM_{2.5}$ (a–c, μg/m³), precipitation (d–f, mm/day), wind speed (g–i, m/s), temperature (j–l, K), and Planetary Boundary Layer (PBL) height (m–o, m) during the EASM period in 2008 (left), and their mean changes due to meteorological variations in PreG (2009–2013, center) and PostG (2014–2018, right) phase relative to 2008 ($SIM_{Base}$ - $SIM_{MET=2008}$).

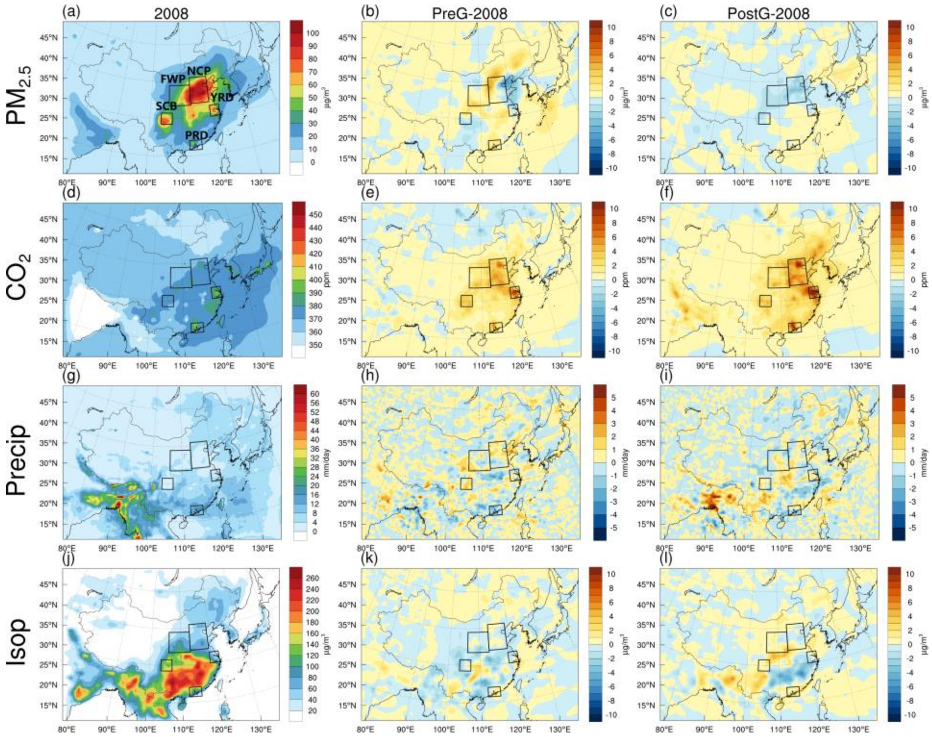


**Figure 5**. The $PM_{2.5}$ (a–c, μg/m³), $CO_2$ (d–f, ppm), precipitation (g–i, mm/day), and isoprene (j–l, μg/m³) during the EASM period in 2008 (left), and their mean changes due to $CO_2$ emission variations in PreG (2009–2013, center) and PostG (2014–2018, right) phase relative to 2008 ($SIM_{Base}$ - $SIM_{CO2=2008}$).

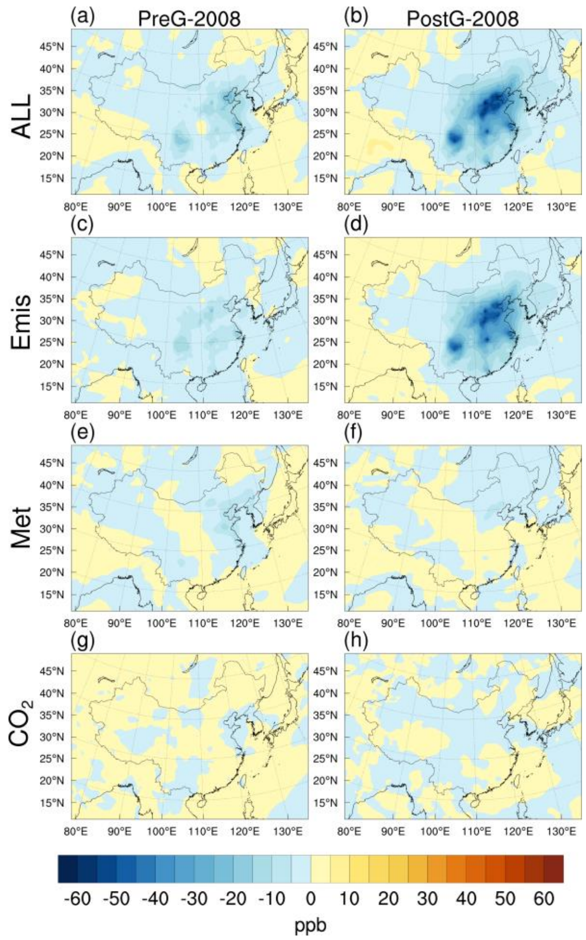



**Figure 6**. The total changes in $PM_{2.5}$ concentrations (All, $SIM_{Base}$ - $SIM_{2008}$), and the changes in $PM_{2.5}$ attributed to variations of anthropogenic pollutant emissions (Emis, All-Met-$CO_2$), meteorological conditions (Met, $SIM_{Base}$ – $SIM_{MET=2008}$), and $CO_2$ emissions ($CO_2$, $SIM_{Base}$ - $SIM_{CO2=2008}$) during the EASM period in PreG (2009–2013, left) and PostG (2014–2018, right) phase relative to 2008.

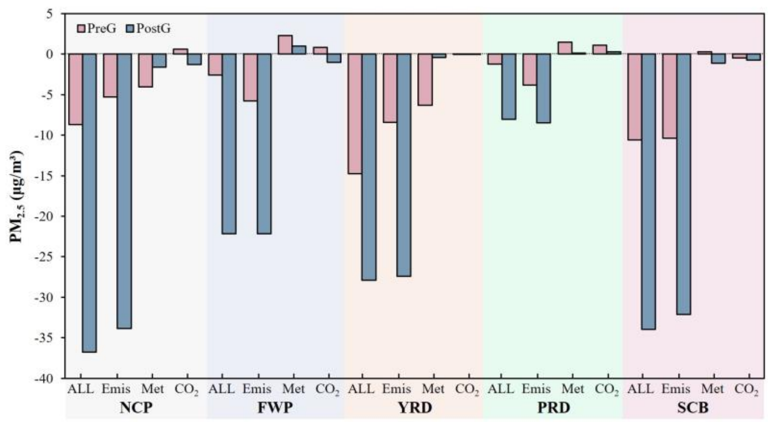



**Figure 7**. The total changes in $PM_{2.5}$ concentrations (All, $SIM_{Base}$ - $SIM_{2008}$) for the North China Plain (NCP), Fenwei Plain (FWP), Yangtze River Delta (YRD), Pearl River Delta (PRD), and Sichuan Basin (SCB) during the EASM period in PreG (2009–2013) and PostG (2014–2018) phase relative to 2008, along with the variations

in $PM_{2.5}$ due to anthropogenic pollutant emissions (Emis, All-Met-$CO_2$), meteorological conditions (Met, $SIM_{Base}$ – $SIM_{MET=2008}$), and $CO_2$ emission ($CO_2$, $SIM_{Base}$ - $SIM_{CO2=2008}$) changes.

14. Figure 4: Correct this caption (currently refers to $O_3$).
**Response**: Thanks. Sorry for the mistake. We replaced $O_3$ with $PM_{2.5}$.

15. Line 237: In Section 3.3 (and same for Section 3.2), it would be useful to reiterate which simulations have been used to generate these results, and include this in the captions for Figure.
**Response**: Thanks for your valuable suggestion. We have reiterated in the text which simulations were used to generate these results and included this information in the figure captions. Revisions to the figure captions are detailed in response to question 13.

Changes in manuscript:

3.1 $PM_{2.5}$ variation

(L220–222): "Changes in $PM_{2.5}$ concentrations from 2009 to 2018 relative to 2008 were quantified by comparing simulation results from each year in the $SIM_{Base}$ experiment with $SIM_{2008}$ ($SIM_{Base}$ - $SIM_{2008}$)."

3.2 Contribution of meteorological conditions

(L287–288): "The impact of meteorological conditions variations on $PM_{2.5}$ concentrations were assed by compared $SIM_{Base}$ results with those from $SIM_{MET=2008}$ for the same year ($SIM_{Base}$ - $SIM_{MET=2008}$)."

3.3 Contribution of $CO_2$

(L326–328): "The contribution of $CO_2$ emission changes to $PM_{2.5}$ variability was quantified by comparing the $SIM_{Base}$ experiment with the $SIM_{CO2=2008}$ experiment ($SIM_{Base}$ - $SIM_{CO2=2008}$) within the same year."

3.4 Contribution of anthropogenic pollutant emissions

(L363–363): "The contribution of changed anthropogenic pollutant emissions to $PM_{2.5}$ variation was determined by removing the effects of meteorological and $CO_2$ emission changes from the total variation."

16. Line 267: Do you mean the average over the entire region?
**Response**: Thanks. This refers to the mean values, and we have revised the ambiguous wording accordingly.

Changes in manuscript:

(L364–365): "During the PreG period, $PM_{2.5}$ levels decreased by an average of 5 to 10 $\mu g/m^3$ over East Asia."

17. Line 283: Correct the units on the legend in this Figure (should be $ug/m^3$).
**Response**: Thanks. Sorry for the mistake. We have correctted the units on the legend in this Figure

Changes in manuscript:

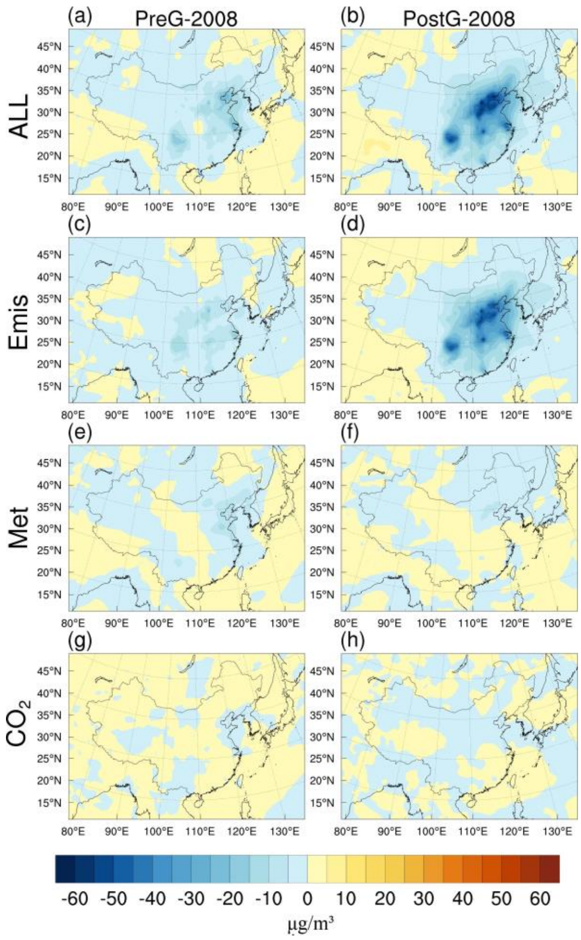



**Figure 6.** The total changes in $PM_{2.5}$ concentrations (All, $SIM_{Base}$ - $SIM_{2008}$), and the changes in $PM_{2.5}$ attributed to variations of anthropogenic pollutant emissions (Emis, All-Met-$CO_2$), meteorological conditions (Met, $SIM_{Base}$ – $SIM_{MET=2008}$), and $CO_2$ emissions ($CO_2$, $SIM_{Base}$ - $SIM_{CO2=2008}$) during the EASM period in PreG (2009–2013, left) and PostG (2014–2018, right) phase relative to 2008.

18. In the simulations where meteorology varies with the year and you see an increase in temperature, would the model also have simulated an increase in BVOC emissions? If so that needs to be discussed.

**Response**: Thanks. As shown in Table 1, the only difference between the $SIM_{Base}$ and $SIM_{MET=2008}$ experiments lies in the meteorological conditions. Therefore, the difference $SIM_{Base}$ − $SIM_{MET=2008}$ represents the impact of meteorological changes on $PM_{2.5}$. Although elevated temperatures may lead to changes in BVOC emissions, Figure R1 indicates that BVOC changes are not significant and show little spatial correlation with $PM_{2.5}$ trends (Figure 4 a-c). As a result, this aspect is not discussed further in the manuscript.

**Table 1.** The Numerical experimental in this study

| Experiment | Time | Meteorological | $CO_2$ | Anthropogenic |
|---|---|---|---|---|

| | | fields | emissions | pollutant emissions |
|---|---|---|---|---|
| $SIM_{2008}$ | 2008 | 2008 | 2008 | 2008 |
| $SIM_{Base}$ | 2009-2018 | 2009-2018 | 2009-2018 | 2009-2018 |
| $SIM_{MET=2008}$ | 2009-2018 | 2008 | 2009-2018 | 2009-2018 |
| $SIM_{CO2=2008}$ | 2009-2018 | 2009-2018 | 2008 | 2009-2018 |

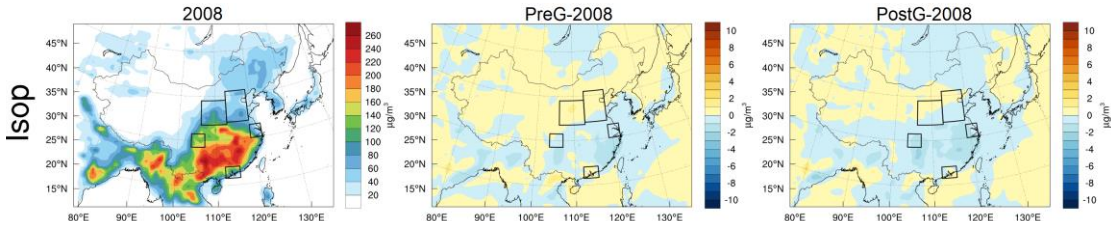



**Figure R1.** The isoprene (μg/m³) during the EASM period in 2008 (left), and the changes due to meteorological variations in PreG (2009–2013, center) and PostG (2014–2018, right) phase relative to 2008 ($SIM_{Base}$ - $SIM_{MET=2008}$).

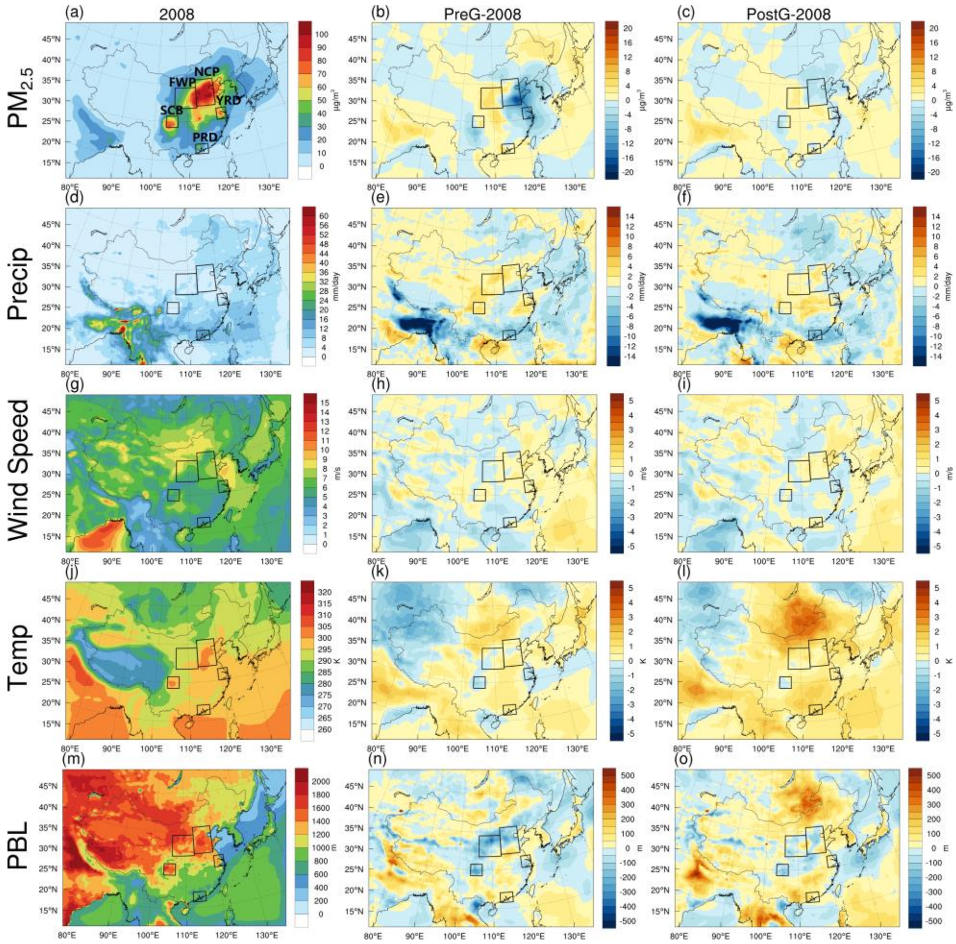



**Figure 4**. The $PM_{2.5}$ (a–c, μg/m³), precipitation (d–f, mm/day), wind speed (g–i, m/s), temperature (j–l, K), and Planetary Boundary Layer (PBL) height (m–o, m) during the EASM period in 2008 (left), and their mean changes due to meteorological variations

in PreG (2009–2013, center) and PostG (2014–2018, right) phase relative to 2008 ($SIM_{Base}$ - $SIM_{MET=2008}$).