

Dear Editor,

Thank you very much for your and the reviewers' thoughtful and constructive comments on our manuscript. We have carefully addressed all comments and suggestions point by point and have revised the manuscript accordingly. Detailed responses to the reviewers' comments are provided below (*in blue*), and all corresponding revisions are highlighted *in red* in the revised manuscript.

Thank you very much for your time and consideration!

We are looking forward to hearing from you.

Sincerely,

Yunjiang Zhang, on behalf of all co-authors

Nanjing University of Information Science and Technology, Nanjing, China

Email address: yjzhang@nuist.edu.cn

Response to the Referee

The authors have satisfactorily addressed all of my previous comments and concerns. I also note that the responses to the other reviewers' comments are thorough and that appropriate revisions have been made accordingly. Overall, the manuscript is substantially improved, and I believe it is close to being suitable for publication after the authors address the following new minor issues:

Response: We sincerely appreciate the reviewer's positive and constructive feedback on our manuscript. Your suggestions have been invaluable in enhancing the quality and clarity of our work. We have thoroughly revised the manuscript in response to your comments and believe that these changes have significantly improved it. Thank you again for your insightful input.

Line 88: Please revise "machine learning-based framework" to "machine learning-based model framework."

Response: Revised.

Line 89: Replace "respective roles" with "relative contribution."

Response: Replaced.

Line 145: Replace "errors" with "uncertainty."

Response: Replaced.

Line 196: Please carefully evaluate the use of "significant" or "significantly" throughout the manuscript, especially where no significance test is provided. In addition, could the authors offer a numerical range for the uncertainty reduction here?

Response: Thank you for your insightful suggestions. We carefully reviewed the use of "significant" and "significantly" throughout the manuscript and confirmed that these terms were indeed used in contexts without significance testing. To more accurately convey our results, we have removed "significant" from the revised text and included specific descriptions of the uncertainty reduction. The modified content is as follows:

Notably, inclusion of time-related variables could reduce model uncertainty compared to simulations excluding these predictors. The average uncertainty decreased by approximately 2–4% at the regional-mean level (Fig. S3).

Line 200: The description should be improved. The authors may directly state that the x-axis represents the years used for model training, and the y-axis represents the years predicted by the trained model.

Response: Thank you for your suggestion. We have revised the description for clarity, stating that the x-axis represents the years used for model training, while the y-axis indicates the years predicted by the trained model. This clarification should enhance the reader's understanding of the figure.

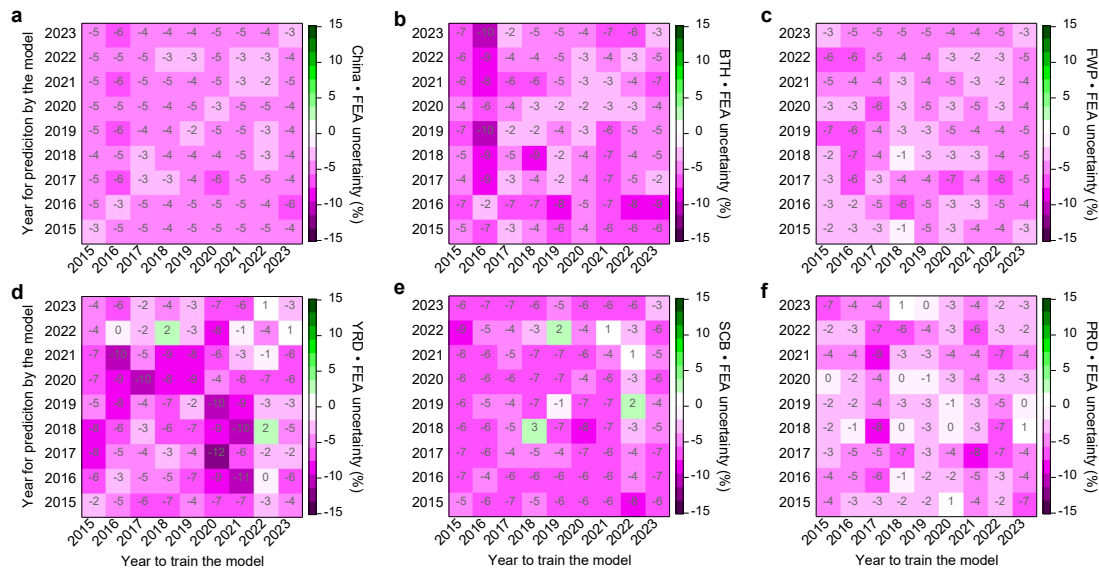


Figure 2. Uncertainty assessment of the FEA method. The uncertainty for the FEA method is calculated using the approach described in Text S2. The x-axis represents the years used for model training, and the y-axis represents the years predicted by the trained model. The diagonal line in each sub-panel represents the changes in the residuals of the models.

Line 270: The abbreviations "BTH" and "YRD" should be defined upon first use. Also, Lines 278–279 contain redundant definitions, please remove duplicates.

Response: Thank you for your suggestion. We have defined the abbreviations "BTH" (Beijing-Tianjin-Hebei) and "YRD" (Yangtze River Delta) upon their first use in the manuscript in line 66. Additionally, we have removed the redundant definitions found in lines 278-279 to ensure clarity and conciseness. We also conducted a thorough review of the entire manuscript to ensure that all abbreviations and their corresponding full terms are used correctly and consistently.

Lines 289–291: I suggest removing this sentence, as a similar concluding remark has already been presented earlier.

Response: Thank you for your suggestion. We have removed it.

Line 301: Please replace “first phase” with “Phase I,” and ensure consistent formatting for subsequent phases.

Response: Thank you for your suggestion. We have made the requested change by replacing "first phase" with "Phase I" and have ensured consistent formatting for all subsequent phases throughout the manuscript.

Line 361: I recommend removing the phrase “suggesting that ozone responses to further emission reductions may have reached a saturation point.”

Response: Thank you for your suggestion. We have removed the phrase.

Line 399: Please clarify which region “f” refers to in this context.

Response: Thank you for your comment. We have clarified in the figure legend that "f" represents the overall conditions across the five regions, and we have added relevant annotations on the y-axis of "f" for further clarification.

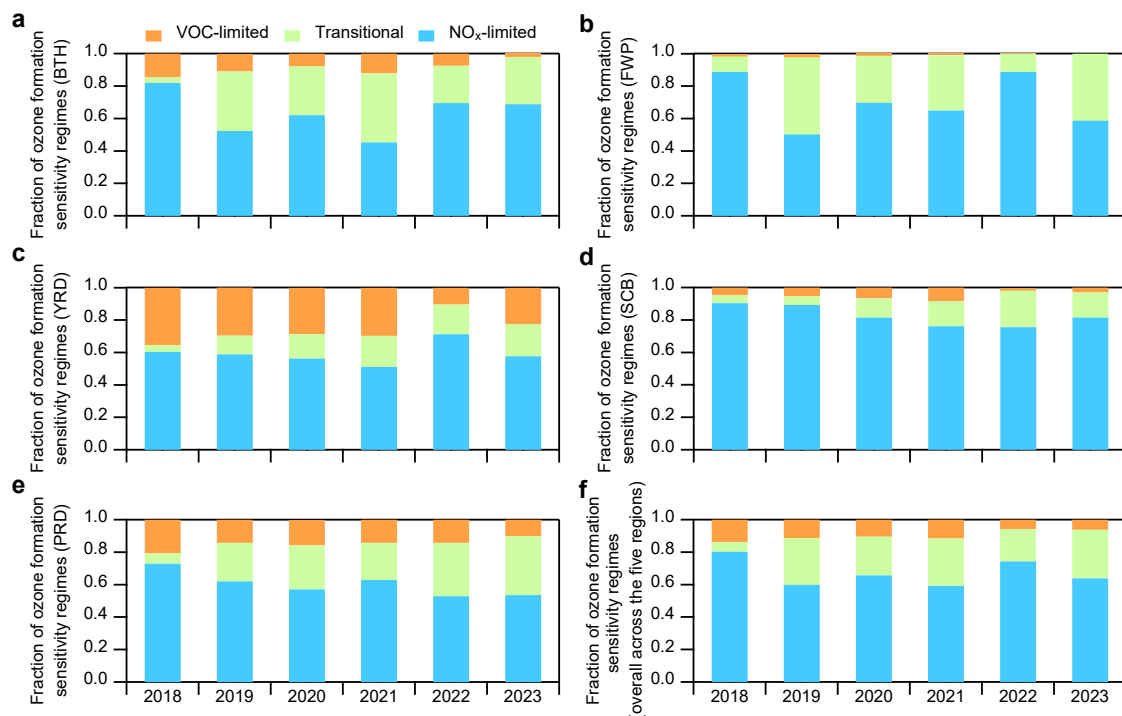


Figure 6. Trends in the distributions of ozone production sensitivity regimes. Fractions of VOC-limited, NO_x-limited, and transitional ozone sensitivity regimes across five key regions during the summertime (June to August) from 2018 to 2023, based on the FNR analysis. **a-e** the trend across the five city cluster regions in China during the summer months (June, July, and August): BTH, FWP, YRD, SCB, and PRD, respectively. **f** presents the overall trends for all five regions.

Line 418: It would be more accurate to state that the analysis “provides an indication of meteorological conditions” rather than drawing a direct conclusion.

Response: Thank you for your suggestion. We have revised the sentence for greater accuracy. The modified content is as follows:

The following summer (2023) featured anomalously heavy rainfall, resulting in sharp ozone suppression ($-17.8 \pm 2.3 \mu\text{g m}^{-3}$ in the YRD and $-9.7 \pm 3.3 \mu\text{g m}^{-3}$ in the SCB). This reduction coincided with a remarkable increase in precipitation, i.e., 102% in YRD and 35% in SCB (Fig. S14), indicating that rainy meteorological conditions may have suppressed ozone production.

Lines 436–438: This sentence can be further streamlined for clarity.

Response: Thank you for your suggestion. We have streamlined the sentence for clarity. This modification improves the clarity of the statement while retaining its original meaning. The modified content is as follows:

Consistent with these findings, Yang et al. (2024) reported that high-temperature and low-RH conditions over the NCP and YRD could enhance photochemical ozone formation, with chemical production dominating during peak pollution periods.

Line 463: Please revise the section title to “Reshaping distributions of ozone by climate change and emission controls.”

Response: Revised.

Line 477: A brief clarification of the scenarios referenced here would be helpful, as the current wording is vague even though earlier sections describe them in detail.

Response: Thank you for your suggestion. To improve clarity, we have added a brief clarification of the scenarios referenced in Line 477. The modified content is as follows:

Three sensitivity simulations (see Section 2.5 and Fig. S21) confirm this robustness: trend slopes range from $0.11\text{--}0.14 \mu\text{g m}^{-3} \text{ yr}^{-1}$ in BaseBTH (high-pollution scenario), $0.05\text{--}0.10 \mu\text{g m}^{-3} \text{ yr}^{-1}$ in the BaseYRD (moderate-pollution scenario), and $0.03\text{--}0.10 \mu\text{g m}^{-3} \text{ yr}^{-1}$ in the BasePRD (low-pollution scenario).

Line 525: Please check whether “anthropogenic precursor emissions” refers specifically to HCHO here and revise accordingly for accuracy.

Response: We thank the reviewer for raising this point. In the original text, anthropogenic precursor emissions was not intended to refer only to HCHO, but rather to the combined influence of multiple anthropogenic ozone precursors, including NO_x, CO, and anthropogenic VOCs. To avoid potential ambiguity, we have revised the sentence to explicitly clarify this broader definition. The revised text now reads:

Our results revealed that increased anthropogenic emissions were the dominant driver of the sharp rise in summertime MDA8 ozone concentrations during the Phase I, contributing an average increase of $23.2 \pm 1.1 \mu\text{g m}^{-3}$.

Line 538: I suggest removing the word “growing.”

Response: Removed.

Lines 550–551: The conclusion should be reframed to indicate that a warming climate modulates the long-term evolution of ozone trends. The subsequent sentence may then be adjusted for a smoother logical transition.

Response: Thank you for your insightful suggestion. We have reframed the conclusion to indicate that a warming climate modulates the long-term evolution of ozone trends, and we adjusted the subsequent sentence for a smoother logical transition. The modified content is as follows:

Good correlations between the modelled ozone and surface temperature ($r = 0.72\text{--}0.93$) across major urban clusters indicated that climate warming exerts a persistent control on the long-term evolution of ozone. While reductions in precursor emissions have improved ozone control efficiency, the direct enhancement of ozone by rising temperatures increasingly interferes with, and in some regions may partially offset, the air-quality benefits achieved through emission mitigation. Together, these findings highlight that effective ozone management in a warming world will require integrated strategies that jointly address emission reductions and climate adaptation.