**Response to Reviewer 01:**

This study evaluates the variation in tropospheric ozone levels, trends, photochemical regimes, and radiative effects using the global chemistry-climate model ECHAM6–HAMMOZ and satellite data from 1998 to 2019. It examines how anthropogenic emissions of nitrogen oxides and volatile organic compounds affect ozone production. The global trend in tropospheric ozone is increasing, with simulations showing strong agreement with satellite data, which is in accordance with previous studies. The study also explores how changes in pollution emissions impact ozone trends and photochemical regimes. Doubling emissions of nitrogen oxides and volatile organic compounds leads to different ozone trends compared to halving these emissions, with region-specific responses observed in different parts of the world.

The manuscript explores an important and timely topic regarding the climate and health impacts of tropospheric ozone, which holds great relevance. To further enhance the clarity and impact of the work, however, it is recommended revisiting some language elements to improve readability. Additionally, some of the figures would benefit from improvements in quality; they appear somewhat small, with low resolution, and the axis labels and legends could be more legible.

**Response:** We sincerely thank the reviewer for the meticulous review, constructive comments, and valuable suggestions, which have significantly enhanced the quality of the manuscript. As suggested by the reviewer, we have carefully addressed all suggestions and incorporated them. Additionally, we have corrected grammatical and typographical errors throughout the manuscript to ensure clarity and readability. Figures have been modified to improve their readability. We appreciate the reviewer's time and effort in improving our work. Changes are indicated in track mode version of the manuscript at a line number indicated in the replies.

Content-wise, there are several key points that also need to be revised to bring the manuscript to publication standard. Addressing those specifically will be essential to enhance the clarity and impact of the results:

1. The introduction lacks structure. Model and observational data from the literature are presented in a mixed way, as are global and regional findings. Chemical symbols such as NOx, NOy, and VOC need to be defined or explained right from the beginning. In addition, the abbreviations used for the sensitivity experiments are not well chosen, as they could be mistaken for names of chemical species.

   **Response:** We appreciate the reviewer's suggestions. We have revised and reorganized the introduction to improve its overall structure and clarity. Additionally, we have defined chemical symbols at their first appearance to enhance readability and prevent ambiguity. To avoid confusion, we have also refined the abbreviations used for

sensitivity experiments as (2) doubling anthropogenic emission of NOx globally (DoubNOx), (3) reducing anthropogenic emissions of NOx by 50 % globally (HalfNOx), (4) doubling anthropogenic emissions of all VOCs globally (DoubVOC), (5) reducing anthropogenic emissions of all VOCs by 50 % globally (HalfVOC). (See L252-258 in section 2.5).

2. The manuscript does not specify which emission scenario from ACCMIP (Representative Concentration Pathway - RCP) is used. A rationale or justification for the selection of sensitivity experiments regarding NOx and VOC emissions is currently missing, and providing this context would strengthen the study's approach. Are there real-world examples for this? What exactly is being investigated beyond the well-known fact that these are the primary drivers of tropospheric ozone?

   **Response:** We appreciate the reviewer's concern and clarify that our model simulations use the RCP 8.5 high-emission scenario from ACCMIP (Van Vuuren et al., 2011), chosen for its relevance in representing strong anthropogenic impact. The ACCMIP inventory includes emissions from multiple sectors, making it a robust dataset for evaluating atmospheric composition changes. This is already mentioned in the manuscript [Line No:257-258].

   Our sensitivity experiments, doubling and halving global NOx and VOC emissions aim to quantify ozone, ozone photochemical regime and radiative forcing changes due to anthropogenic emission changes rather than just reaffirm their known role. This approach of increase/decrease of emissions is important for nonlinear response of ozone to emissions. These experiments are helpful for designing emission implementation strategies (e.g., Zhang et al., 2021; Wang et al., 2023). These points have been incorporated into the revised introduction for clarity and context (L146-149).

3. It would be important to differentiate regionally more when describing the relationships between NOx and VOC development. In addition, a more detailed discussion of the effects of different VOC species would also be helpful. And, it is worth considering whether natural VOC emissions in different geographical regions might play a significant role. Despite their considerable contribution natural VOCs are not addressed at all.

   **Response:** Thank you for your valuable comment. We acknowledge the importance of regional differentiation and the role of natural VOC emissions in ozone formation. However, our study focuses primarily on the impact of anthropogenic NOx and VOC emissions on global ozone trends and photochemical regimes. We believe that adding additional analysis of natural VOCs will lose the focus of the manuscript and make it

very lengthy. Therefore we think that this should be the focus of a separate study where the ozone sensitivity to natural VOCs is investigated in detail.

4. It is well-known that temperature and humidity have a significant impact on the life cycle of ozone. The most obvious explanation for the positive ozone trend - climate warming - is not discussed in this study, which is a major shortcoming.

   **Response:** We acknowledge the reviewer's concern regarding the role of climate warming in tropospheric ozone changes. However, our study primarily focuses on assessing the impact of anthropogenic emission changes on tropospheric ozone over the 21-year period from 1998 to 2019. Given this relatively short time frame, the direct impact of climate change on ozone levels is expected to be minimal.

   According to the IPCC AR6, the rate of global temperature increase during our short study period is approximately 0.3 to 0.4°C. As highlighted by Zanis et al. (2022), an ozone climate penalty, where higher temperatures contribute to ozone increases, typically emerges only after global temperatures rise by 2–3°C. Even then, this penalty is observed primarily at the surface in high-emission regions. Furthermore, climate change-induced increases in water vapour generally reduce ozone lifetime in remote regions, leading to net ozone reductions rather than increases.

   While we recognize the importance of climate change in shaping future ozone distributions, our study is focused on identifying the more immediate and dominant driver, that is, changes in anthropogenic emissions over the past two decades, and their impact on ozone photochemical regimes and trends. The conclusion section has been revised in the manuscript to include the above points (L1152-1168).

   Zanis, P., Akritidis, D., Turnock, S., Naik, V., Szopa, S., Georgoulias, A.K., Bauer, S.E., Deushi, M., Horowitz, L.W., Keeble, J. and Le Sager, P., 2022. Climate change penalty and benefit on surface ozone: a global perspective based on CMIP6 earth system models. Environmental Research Letters, 17(2), p.024014.

5. The conclusions section is more of a listed summary of findings rather than a true conclusion. What would be the interpretation of your findings, for example regarding current and future mitigation measures in a warming climate and changing natural sources?

   **Response:** We appreciate the reviewer's suggestion. We included a summary of the results as we believe it is important to mention the key points of our assessment of trends, photochemical regimes, and radiative effects. In addition to this, we have now also revised the Conclusions section to include a discussion paragraph that provides

further interpretation of our results. This discussion elaborates on the implications of our findings regarding current and future mitigation strategies in the context of a warming climate and evolving emission sources.