Manuscript No.: egusphere-2025-5734

Responses to Editor

Recommendations to address the reviewer's comments on novelty. In the manuscript and in the response the focus on the novelty is the approach. However, a main reason to have a novel approach is to also have improved or more detailed or new findings. The focus of the authors on the novelty have been more on the former and not on the latter. Thus, in order to highlight how this new approach has had an impact on the knowledge of atmospheric chemistry in Africa, I recommend adding in a comparison to previous studies. This will articulate the scientific novelty more clearly. In addition to those discussed in the review and response, I have made a recommendation at the end. In addition, I would recommend that the ground-based measurements that do exist are included to also highlight the model performance in present day. I have indicate below where ozone data for South Africa can be downloaded. Depending on performance, it could also be a key finding - as we do know that many models struggle to accurately capture atmospheric composition in Africa. I have also made some comments about biomass burning and its potential impact that may be helpful.

We thank the editor for this overarching guidance. We have revised the manuscript and response to emphasize the scientific findings enabled by our approach. Specifically, we now compare our results with Turnock et al. (2022), Brown et al. (2022), and the UNEP–AUC–CCAC Integrated Assessment, while explaining the differences. We also added a present-day evaluation using SAAQIS observations, which shows moderate spatial agreement but a positive bias. Its implications and spatial sampling limitations are now stated. Finally, we revised the discussion of precursor sensitivity and biomass burning, added the suggested SAFARI 2000 and Archibald et al. (2010) references, and clarified that biomass burning emissions are held fixed in the sensitivity experiments. Together, these changes clarify the physical interpretation, scope, and limitations of our findings, and show how they complement studies of future emission controls.

Line 400: Should acknowledge these are old sources, would not be constant across the continent (in growing urban areas it is not NO_x limited) and it is not true across all seasons (e.g. biomass burning emissions of NO_x can result in VOC limited regimes). SAFARI2000 has a lot of information on biomass burning and links to ozone in southern Africa.

Response:

We thank the editor for this important comment. We agree that our previous statement was overly broad and that the older references cited there do not support a continent-wide and seasonally invariant NO_x-limited regime. We have therefore removed this statement and clarified that the VOCs-to-NO_x emission ratio is used only as a simplified proxy in the RF model, rather than as a definitive diagnostic of the O_3 production regime.

We now explicitly acknowledge that precursor sensitivity varies across Africa and by season. In particular, rapidly urbanizing NO_x-rich environments and dry season biomass burning plumes may favor VOC-sensitive conditions and can substantially affect O_3 production, especially over southern Africa. We added references to the SAFARI 2000 (Swap et al.,2003) and recent work (Wang et al., 2025) on the roles of biomass burning and anthropogenic emissions in southern African O_3.

We also clarified that the O_3_NAT experiment isolates the response to climate-driven changes in biogenic isoprene while biomass burning and other non-isoprene precursor emissions are held fixed at their baseline values. Therefore, the simulated O_3 decrease is an annual mean and model-derived response to this isolated perturbation over Central and Western Africa, and is not interpreted as applying to all urban or biomass burning-influenced regions or seasons. We added a corresponding caveat to the seasonal results discussion, abstract, conclusion, and limitations section.

Line 421: This is also biomass burning period that is strongly linked with ozone production. Archibald et al 2010 has the timing to burning in southern Africa that might be useful here. Climate and the inter-annual variability of fire in southern Africa: a meta-analysis using long-term field data and satellite-derived burnt area data. (https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1466-8238.2010.00568.x)

Response:

We thank the reviewer for this helpful comment. We agree that SON overlaps with the late dry season biomass burning period over much of southern Africa, during which fire emissions can strongly influence regional O_3 production through emissions of NO_x and VOCs.

We clarify that Fig. S5a represents the O_3_MET experiment, in which meteorological fields vary but biogenic isoprene emissions are fixed at their 2020 values. The similar O_3 decrease in Fig. S5a and Fig. S5c indicates that, within our sensitivity approach, the projected SON decrease over southern Africa is mainly driven by changes in meteorological conditions rather than by the climate-driven change in biogenic isoprene emissions.

This result does not imply that biomass burning is unimportant for seasonal O_3 in southern Africa. Biomass burning emissions are held fixed in our experiments. Consequently, the present analysis cannot quantify the effect of future changes in fire activity or fire-derived NO_x on SON O_3 or on the O_3 production regime. We have clarified this experimental scope in the manuscript and added the suggested reference by Archibald et al. (2010), together with a

SAFARI 2000 reference.

Line 507: This can be partially addressed by validating the model with ground-based measurements that do exist. For example, in South Africa there are definitely ozone measurements available through SAAQIS https://saaqis.environment.gov.za/

Response:

We thank the editor for this important suggestion. We added a new observational evaluation of RF-predicted near-surface O_3 using data from the South African Air Quality Information System (SAAQIS) (new Fig. S1). We selected 94 monitoring sites with observations available for at least three years during 2020–2025.

To ensure consistency with the 2° × 2.5° model resolution, we first calculated the 2020–2025 mean observed O_3 concentration at each eligible site and then averaged all site observations within each model grid cell. This yielded 11 grid-cell mean observations, which were compared with RF-predicted O_3 averaged over 2020–2025 and across the four SSP scenarios.

The RF predictions reproduce a moderate degree of spatial variability across South Africa (R = 0.54), but show a systematic positive bias relative to observations (MAE = 11.92 ppb, RMSE = 12.93 ppb, NMB= 46.7%). The grid-cell averaging reduces the point-to-grid representativeness mismatch. Nevertheless, the available sites are concentrated around the Pretoria metropolitan area and coastal South Africa. The evaluation therefore does not provide spatially uniform validation across the African continent, and unresolved urban, topographic, and coastal processes may still contribute to the mismatch.

We have added these results and limitations to the manuscript. We also clarify that the positive bias in present-day absolute O_3 concentrations introduces uncertainty into absolute future O_3 levels and associated health estimates. However, present-day bias alone does not directly quantify the biases in projected O_3 changes between 2050 and 2020, because persistent biases may partially offset in the calculation of differences.

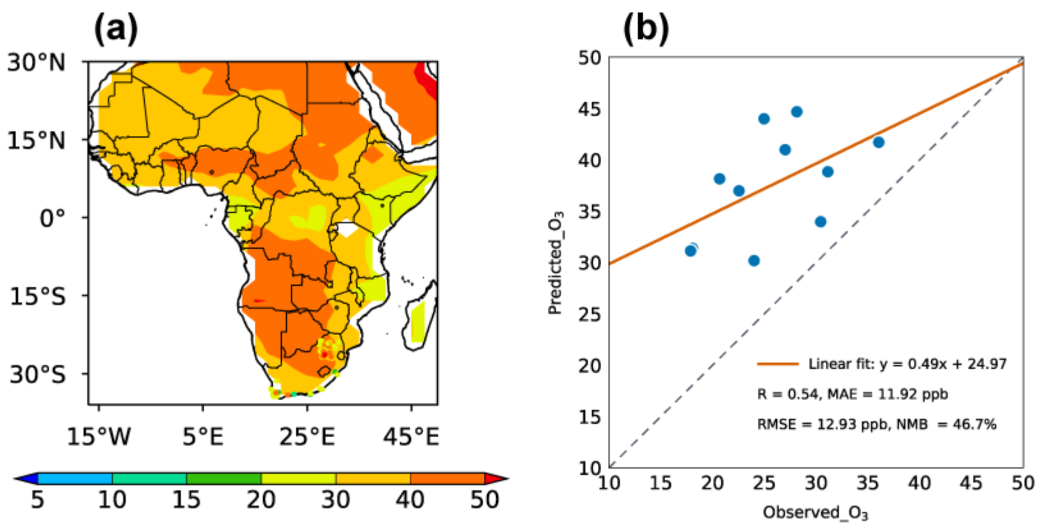

Figure S1. Evaluation of RF-predicted near-surface O_3 concentrations against observations from the South African Air Quality Information System (SAAQIS) during 2020–2025. (a) Spatial distribution of RF-predicted O_3 concentrations (ppb), averaged across the four SSP scenarios, with observations from 94 monitoring sites overlaid. Sites with valid observations for at least three years during 2020–2025 are included. (b) Comparison between RF-predicted and observed O_3 concentrations after averaging station observations within each 2° × 2.5° model grid cell (N = 11). The grey dashed line denotes the 1:1 line and the orange line denotes the least-squares regression fit.

Line 523: How do the results here compare with previous studies? This should include the Integrated assessment from UNEP, AUC, and CCAC that modeled ozone and its impacts now and into the future (though the future runs only change African GHG emissions and not global, so a different set-up).

Response:

We thank the editor for this constructive suggestion. We have added a dedicated comparison with previous studies and with the UNEP–AUC–CCAC Integrated Assessment of Air Pollution and Climate Change for Sustainable Development in Africa (UNEP, 2023). We now compare our results with Turnock et al. (2022) and Brown et al. (2022), which reported differing future O_3 responses over Africa under SSP3-7.0.

We also clarify the important difference in experimental design. The UNEP–AUC–CCAC Assessment used GISS-E2.1-G to evaluate African emission mitigation scenarios, while emissions outside Africa were prescribed following SSP3-7.0. It found that the SLCP and Agenda 2063 mitigation scenarios reduce population-weighted O_3 exposure and estimated that the Agenda 2063 scenario could avoid approximately 40,000 ± 13,000 O_3-related premature deaths per year by 2030 and 320,000 ± 100,000 per year by 2063 relative to its baseline scenario. In contrast, our sensitivity experiments isolate climate-driven meteorological and biogenic isoprene effects while holding non-isoprene precursor inputs fixed. Therefore, the two studies are complementary rather than directly numerically comparable. The assessment indicates that African emission controls can substantially reduce O_3 exposure and health burdens, but that such benefits may be partly offset by the climate-driven O_3 increases identified here.

Reference:

Archibald, S., Nickless, A., Govender, N., Scholes, R. J., and Lehsten, V.: Climate and the inter-annual variability of fire in southern Africa: a meta-analysis using long-term field data and satellite-derived burnt area data, Glob. Ecol. Biogeogr., 19, 794–809, https://doi.org/10.1111/j.1466-8238.2010.00568.x, 2010.

Brown, F., Folberth, G. A., Sitch, S., Bauer, S., Bauters, M., Boeckx, P., Cheesman, A. W., Deushi, M., Dos Santos Vieira, I., Galy-Lacaux, C., Haywood, J., Keeble, J., Mercado, L. M., O'Connor, F. M., Oshima, N., Tsigaridis, K., and Verbeeck, H.: The ozone-climate penalty over South America and Africa by 2100, Atmos. Chem. Phys., 22, 12331–12352, https://doi.org/10.5194/acp-22-12331-2022, 2022.

Swap, R. J., Annegarn, H. J., Suttles, J. T., King, M. D., Platnick, S., Privette, J. L., and Scholes, R. J.: Africa burning: A thematic analysis of the Southern African Regional Science Initiative (SAFARI 2000), J. Geophys. Res. Atmos., 108, 8507, https://doi.org/10.1029/2003JD003747, 2003.

Turnock, S. T., Allen, R., Archibald, A. T., Dalvi, M., Folberth, G., Griffiths, P. T., Keeble, J., Robertson, E., and O’Connor, F. M.: The future climate and air quality response from different near-term climate forcer, climate, and land-use scenarios using UKESM1, Earth's Future, 10, e2022EF002687, https://doi.org/10.1029/2022EF002687, 2022.

United Nations Environment Programme (UNEP): Integrated Assessment of Air Pollution and Climate Change for Sustainable Development in Africa, Nairobi, 2023.

Wang, Y., Li, K., Chen, X., Yang, Z., Tang, M., Campos, P. M. D., Yang, Y., Yue, X., and Liao, H.: Revisiting the high tropospheric ozone over southern Africa: role of biomass burning and anthropogenic emissions, Atmos. Chem. Phys., 25, 4455–4475, https://doi.org/10.5194/acp-25-4455-2025, 2025.