Response to Referee #2

Manuscript title

The Dominance and Future Variations of Background Ozone in China under Different Climate and Emission Scenarios

General assessment

Reviewer comment: *This manuscript entitled "The Dominance and Future Variations of Background Ozone in China under Different Climate and Emission Scenarios" investigated the background ozone concentration over China under several emission scenarios. This topic can contribute to understanding the background ozone concentration at the present status and in the future; thus, an important topic could be considered for possible publication in the journal Atmospheric Chemistry and Physics. However, the manuscript also needs to be revised to improve the presentation quality. In particular, the description of the modeling details should be added for a clear explanation of the modeling design. Please address the following comments.*

Response:

We thank the reviewer for the positive assessment of the study's relevance and for the constructive suggestions on improving the presentation and clarifying the modeling framework and experimental design. Each comment has been carefully considered, and the manuscript has been revised accordingly. The reviewer's comments are shown in black italics, our responses in blue, and revised text quoted in this response in blue italics.

Major comments

Reviewer comment: *Emission data (Section 2.2): Are lightning NOx, soil NOx, and biogenic VOCs emissions calculated inline based on the meteorological field? Please clarify this point, and I am wondering whether future states are considered in the calculations of these natural sources.*

Response:

Lightning NO_x, soil NO_x, and biogenic VOC emissions are calculated online in GEOS-Chem using the meteorological fields corresponding to each simulation period and scenario. Therefore, the future simulations explicitly account for the responses of these natural emissions to the projected meteorological conditions under SSP1-1.9 and SSP5-8.5. We have clarified this treatment in Section 2.2 as follows:

"These emissions are calculated online using the meteorological fields corresponding to each simulation period and scenario. Consequently, their responses to projected meteorological conditions are explicitly represented in the future simulations, thereby accounting for climate-sensitive natural precursor emissions that contribute to background ozone formation."

Reviewer comment: *Experimental design (Section 2.3): The description regarding stratospheric ozone is not provided anywhere. First, please describe the treatment of the stratospheric ozone simulation in the GEOS-Chem model for the present years (2011-2014). Second, how can it be treated in the future scenario? Because stratospheric ozone will critically affect the background ozone level, this information is quite important for understanding the findings in this study.*

Response:

This study employs GEOS-Chem v14.2.3 with full-chemistry simulations, in which ozone chemistry from the surface through the stratopause is calculated online using a unified tropospheric–stratospheric chemical mechanism, while ozone above the stratopause is treated with the Linoz linearized parameterization. The concentration and spatial distribution of stratospheric ozone are jointly determined by online chemistry and atmospheric transport and evolve dynamically in response to meteorological and chemical conditions. The present-day (2011–2014) and future (2046–2049) simulations use the same ozone chemistry configuration but are driven by period- and scenario-specific meteorological fields, emissions, and boundary conditions for long-lived chemical species. Consequently, stratospheric ozone and its transport into the troposphere can vary with year and scenario, and their influence on background ozone is captured in the simulation results. These details have now been added to Section 2.1 (Model Description and Meteorological Inputs) of the revised manuscript.

Reviewer comment: *Modeling evaluation of the vertical profile (Section 4, from Line 361): It might be interesting to see the vertical profile; however, the present study only gave the modeling evaluation at the surface level. Thus, these presentations were just the modeling results, and we do not know the validation of these behaviors. Without comprehensive modeling evaluations on the vertical profile, I disagree with presenting such results.*

Response:

Following the reviewer's suggestion, we have added an evaluation of the simulated ozone vertical profiles in Sect. 3 and included the corresponding comparison in Fig. S1.

"To further evaluate the model's ability to reproduce the vertical structure of ozone, seasonal mean ozone profiles from GEOS-Chem were compared with long-term ozonesonde observations (Fig. S1). The simulated profiles agree well with the observations in spring, autumn, and winter, with correlation coefficients of 0.94–0.97

and normalized mean biases ranging from −2.9% to +10.7%. The correlation for the full summer profile is relatively weak (R = 0.23), largely due to a pronounced ozone maximum observed near 1 km. However, correlations increase to 0.92 and 0.85 when evaluated separately over the 0–1 and 1–5 km altitude ranges, respectively, indicating that the model reasonably captures the vertical variation within both ranges. The underestimation of boundary-layer ozone may partly reflect differences in temporal sampling, as afternoon ozonesonde measurements capture higher ozone concentrations associated with stronger photochemical production, whereas daily mean model values smooth out the corresponding afternoon peak. Thus, GEOS-Chem reproduces the main features of the seasonal ozone profiles, with particularly close agreement in the free troposphere."

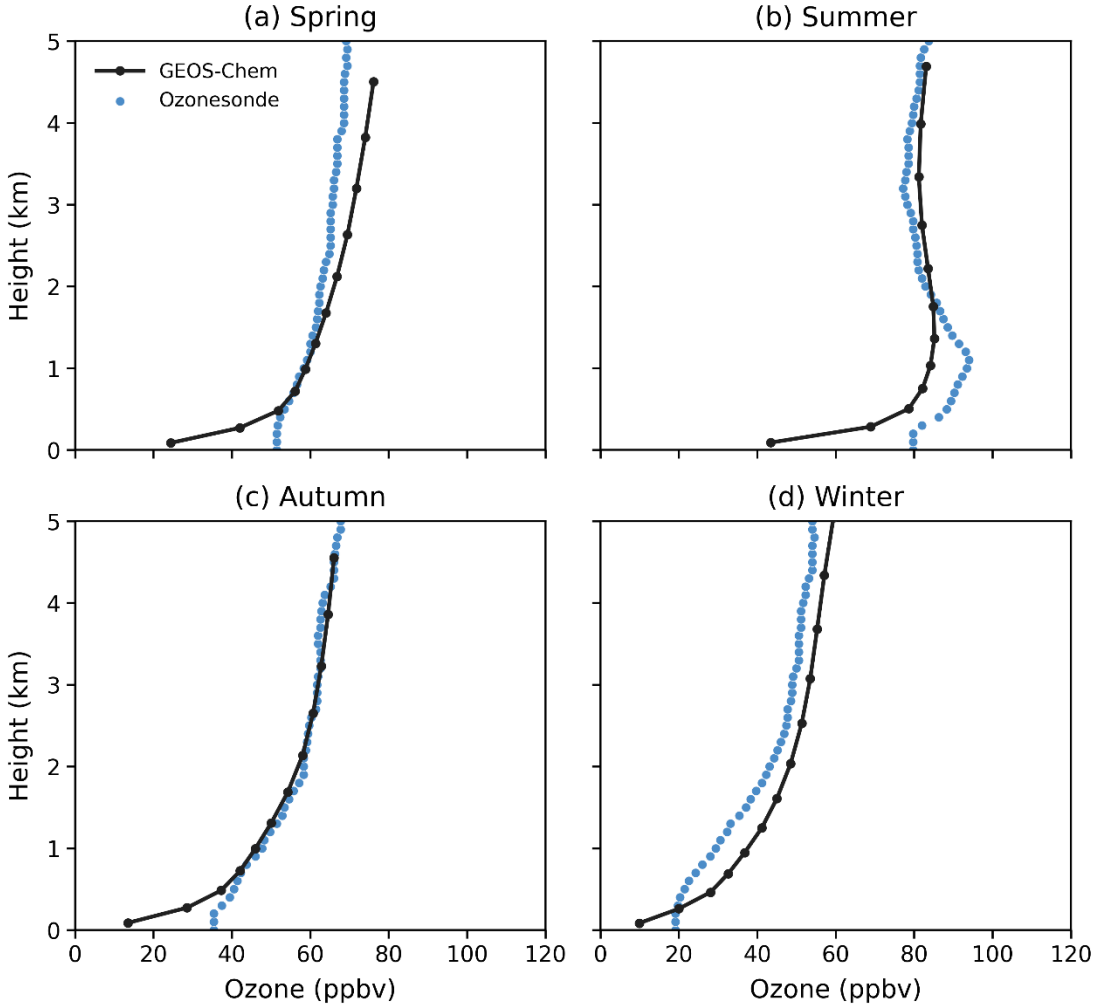


Figure S1. The vertical profiles of seasonal mean ozone at the Beijing Nanjiao Meteorological Observatory (39.81°N, 116.47°E) in (a) spring, (b) summer, (c) autumn, and (d) winter from GEOS-Chem simulation and ozonesonde observations reported by Zhang et al. (2021).

Specific comments

Reviewer comment: Abstract: The specific name (e.g., GEOS-Chem) and abbreviations (e.g., GCAP) should be avoided in the Abstract section without definitions.

Response:

The Abstract has been revised to identify GEOS-Chem explicitly as a chemical transport model and to spell out the Global Change and Air Pollution version 2.0 framework. The entire manuscript has also been checked to ensure that all abbreviations are defined at first use.

Reviewer comment: Model evaluations based on the statistical scores: The authors presented the statistical scores of R and NMB, and concluded that the model can capture the large-scale spatial and seasonal ozone variations. However, the benchmark in terms of modeling performance has been recommended in a previous study (i.e., https://doi.org/10.5194/acp-25-4233-2025), and the authors need to reconsider these presentations.

Response:

Following the reviewer's recommendation, we have incorporated the model-performance criteria proposed by Huang et al. (2025) and revised the interpretation of our R and NMB results accordingly. The following text has been added to the revised manuscript (Lines 240–250):

"Huang et al. (2025) proposed reference criteria of $R > 0.60$ and $|NMB| < 30\%$ for ozone model applications over China, which represent a level of performance considered acceptable in most existing studies. Against these benchmarks, the present simulation meets both criteria in winter and autumn, indicating a reasonable reproduction of seasonal mean concentrations and large-scale spatial distributions. In spring and summer, NMB remains within its recommended range, whereas R falls below its corresponding threshold, indicating a limited ability to resolve fine-scale spatial variability among monitoring sites. Despite these seasonal differences in spatial correlation, the model reasonably reproduces the national-scale seasonal cycle and broad spatial features of surface ozone, supporting its application to the large-scale analysis of present and future background ozone over China."

Technical corrections

Reviewer comment: Line 218: Were "mean surface ozone" and "CTO" identical in this study. The wording needs to be consistent throughout the manuscript.

Response:

In this study, CTO and its components are three-dimensional ozone attribution fields defined at each model level, whereas “mean surface ozone” in the original manuscript referred specifically to the mean CTO concentration in the lowest model layer (i.e., at the surface). To avoid ambiguity, we have replaced this expression with “annual mean surface CTO” and revised similar wording throughout the manuscript to clearly distinguish surface concentrations from tropospheric analyses.