Responses to Reviewer 1

Comment 1:

A) The EPICC-Model uses 20 vertical layers, while CAMx and CMAQ use 14. The authors stress the better layer structure in EPICC as "demonstrating superior vertical resolution compared to the 14 layers coordinates used in other two models" especially "for near-surface turbulent mixing and nocturnal stable layer structures." The manuscript should state that the choice for 14 layers is a user configurable choice, not a fixed feature of CAMx and CMAQ. The rationale for this choice needs to be clearly stated. Ideally, all models should use the same 20 layer structure to improve model-to-model consistency and remove a key source of uncertainty in the comparison of model results.

B) CAMx was run with the CB05 photochemistry mechanism, which is an odd choice given that it represents 20-year old science. CAMx v7.00 used in this study includes CB6r4, and CAMx v7.10 released just 6 months later in 2020 includes CB6r5 (the same CAMx mechanism that was adopted by EPICC, while CMAQ was run with CB6r3). This is a critical issue, and the manuscript should include a statement that CAMx includes CB6, and it should present a well-developed rationale for selecting CB05. Ideally, CAMx should be run with CB6 chemistry.

C) The authors state that both CMAQ and CAMx use "default" boundary conditions to specify concentrations on the 45-km outer grid. They go further to state that CMAQ and CAMx rely on their respective default settings, which is not true. There are no preferred "default" or built-in profile boundary conditions implemented or recommended for these models. Both CMAQ and CAMx can utilize the same MOZART global model output data to derive boundary conditions, as was done for EPICC. While I understand that boundary conditions do not appear to have appreciable effects on model results overall, use of consistent boundary conditions is preferable.

D) Some other simple descriptions for CAMx processes are inadequate or inaccurate. The PPM vertical advection solver was not available in CAMx v7.00 or v7.10, so that entry in Table 1 is either incorrect, or the authors used CAMx v7.20 or later. It is inaccurate to state that CAMx employs the YSU vertical diffusion scheme, rather it employs a first-order K-theory approach (apparently like EPICC-Model) where the vertical diffusivities are diagnostically derived from WRF meteorological fields based on the YSU approach. While Table 1 correctly indicates that TUV is used in 2 ways, the text insufficiently describes the process. Both EPICC and CAMx use the full-science TUV as a pre-processor to generate a photolysis rate input file, then internally apply a streamlined TUV version to adjust those for effects from clouds and aerosols. All of this should be stated in the manuscript.

Response to comment 1:

We thank the reviewer for the constructive comments, which have helped us further clarify model configurations and improve the rigor of the manuscript.

A) Regarding the different vertical layer structures used by the three models, the primary reason is that EPICC-Model adopts a terrain-following height coordinate, whereas CAMx and CMAQ employ terrain-following sigma-pressure coordinates. Due to differences in vertical coordinate definitions and internal numerical implementations, it is not feasible to maintain a completely identical vertical layer structure among the three models.

B) We thank the reviewer for this important comment. We acknowledge that CAMx v7.00 includes the more recent CB6r4 mechanism. However, this study was designed to evaluate the operational forecasting systems using their model-specific configurations during the study period, rather than to compare chemical mechanisms. Because the operational CAMx system employed CB05, we retained this mechanism to maintain consistency with the system being evaluated. Replacing CB05 with CB6 would have produced a modified research configuration rather than the operational CAMx configuration. Computational efficiency and forecast timeliness were also considered in the operational configuration because the greater chemical complexity of CB6 increases computational demand. In addition, CB05 has been applied and evaluated in regional CAMx simulations over China (Wen et al., 2021), supporting its practical applicability. We agree that a parallel CB05-CB6 sensitivity experiment would be valuable. However, such an experiment is beyond the scope of the present operational-system evaluation and will be considered in future work. We have clarified the availability of CB6r4 and the rationale for retaining CB05 in Section 2.1. The revised text is as follows:

(Lines 249-256) *Although CAMx v7.00 also supports the more recent CB6r4 mechanism, CB05 was retained because this study aims to objectively evaluate the models using their actual operational forecasting configurations during the study period, rather than to compare or optimize chemical mechanisms. The operational use of CB05 also reflects the computational-efficiency and forecast-timeliness requirements of routine forecasting, and its applicability to regional CAMx simulations over China has been demonstrated in previous studies (Wen et al., 2021)*

Reference:

Wen, W.; Shen, S.; Liu, L.; Ma, X.; Wei, Y.; Wang, J.; Xing, Y.; Su, W. Comparative Analysis of $PM_{2.5}$ and O_3 Source in Beijing Using a Chemical Transport Model. *Remote Sens.* 2021, *13*, 3457. https://doi.org/10.3390/rs13173457.

C) We thank the reviewer for this valuable comment. We acknowledge that the term "default boundary conditions" used in the original manuscript was not appropriate. In this study, the boundary conditions for the 45-km outer domain in CMAQ were generated based on the profile file "avprofile_cb6r3m_ae7_kmtbr_hemi2016_v53beta2_m3dry_col051_row068.csv", with the top and lateral boundary concentrations obtained through vertical interpolation of the species profiles. The initial and boundary conditions for CAMx were prepared using the icbcprep procedure, where the profile file (tc.default) was used to generate the initial condition file (ic.bin) and boundary condition file (bc.bin). The lateral boundaries were specified using constant concentrations from the profile, while the top boundary was treated using a zero-gradient mixing ratio condition. The corresponding profile files and configuration information have been uploaded to the Zenodo repository (https://doi.org/10.5281/zenodo.17055755). As also noted by the reviewer, boundary conditions do not appear to have appreciable effects on the overall model results. Therefore, we retained the boundary condition approaches adopted in this study. The revised sentence is as follows:

(Lines 272-302) *Regarding boundary conditions, the EPICC-Model incorporates MOZART outputs as the initial and lateral background fields, while CMAQ and CAMx use their respective boundary condition preprocessing approaches. Specifically, CMAQ boundary conditions were generated based on the CB6r3 profile file, and CAMx initial and boundary conditions were prepared using the icbcprep procedure with the corresponding profile configuration, which can be found in the Zenodo repository (https://doi.org/10.5281/zenodo.17055755).*

D) We thank the reviewer for identifying these inaccuracies. After re-examining the model configuration, we confirm that CAMx v7.00 was used in this study. The PPM solver was used for horizontal advection, whereas vertical advection was solved using the fully implicit backward Euler method. The original PPM entry for CAMx vertical advection in Table 1 was therefore incorrect and has been corrected. We have also revised the description of vertical diffusion. CAMx does not directly employ the complete online YSU scheme. Instead, it uses a first-order K-theory approach, with vertical diffusivities diagnosed from WRF meteorological fields generated using the YSU boundary-layer parameterization. Finally, we have expanded the description of the photolysis calculations. Both the EPICC-Model and CAMx use the full-science TUV model as a preprocessor to generate photolysis-rate input files. A streamlined TUV module is then applied internally to adjust the photolysis rates for cloud and aerosol effects. These corrections have been made in Table 1 and Section 2.1. The revised text is as follows:

(Lines 236-237) *For vertical diffusion, the EPICC-Model employs a first-order K-theory approach based on the YSU boundary-layer parameterization.*

(Lines 242-246) *CAMx uses PPM for horizontal advection and a fully implicit backward Euler solver for vertical advection. Its vertical diffusion follows a first-order K-theory approach, with vertical diffusivities diagnosed from WRF meteorological fields based on the YSU parameterization. Thus, CAMx does not directly employ the complete online YSU scheme.*

(Lines 268-271) *For photolysis calculations, both the EPICC-Model and CAMx use the full-science TUV model as a preprocessor to generate photolysis-rate input files. A streamlined TUV module is then applied internally to adjust these rates for cloud and aerosol effects.*

Comment 2:

Section 1, lines 64-68: Please include the latest literature citations for CMAQ, CAMx, WRF-Chem, GEOS-Chem.

Response to comment 2:

We appreciate the reviewer's valuable suggestion. In the revised manuscript, we have added updated and representative literature citations for the four widely used chemical transport models (CTMs). Specifically, the references for CMAQ, CAMx, WRF-Chem, and GEOS-Chem have been supplemented to provide more comprehensive descriptions of these models.

For CMAQ, we have added representative publications describing the development and updates of the CMAQ modeling system, including Byun and Schere (2006), Appel et al. (2017), and Appel et al. (2021). For CAMx, the CAMx User's Guide v7.00 (Ramboll, 2020) and related recent applications have been included. For WRF-Chem, the original model development paper by Grell et al. (2005) has been cited. For GEOS-Chem, we have added the GEOS-Chem High Performance (GCHP) model description (Eastham et al., 2018) and the latest GEOS-Chem model reference guide (The International GEOS-Chem User Community, 2025).

Comment 3:

Section 2.1, lines 125-127: Upon my code review, EPICC relies heavily on original codes from CAMx and CMAQ. A simple statement acknowledging and attributing the source code origins of major process-level routines to CAMx and CMAQ should be added here. I see also that previously published papers describing the development of EPICC do not acknowledge the 30-year developmental legacy of these schemes from CAMx and CMAQ. This is a critical omission.

Response to comment 3:

We thank the reviewer for this important comment and agree that the origins of the relevant process-level routines should be clearly attributed. We have revised Section 2.1 to distinguish the routines inherited or adapted from CAMx and CMAQ from the independent framework development and model integration conducted for EPICC. The contributions of CAMx and CMAQ are now explicitly acknowledged. The revised text is as follows:

(Lines 204-211) *The EPICC-Model is a three-dimensional tropospheric CTM developed in China with an independent modular framework (EPICC-Model Working Group, 2025). Several major process-level routines and numerical algorithms were inherited or adapted from CAMx and CMAQ, whose foundational contributions are explicitly acknowledged. Building on these foundations, the EPICC development team designed a modular and plug-in architecture and independently integrated several specialized chemistry treatments, including sulfate formation, heterogeneous HONO production, and N_2O_5 hydrolysis.*

Comment 4:

Section 2.2, lines 199-200: "Therefore, the WRF model used in this study demonstrates high reliability in simulating temperature and humidity." I suggest replacing the subjective words "high reliability" with a more general word like "adequacy". Also, lines 216-217, "Overall, the WRF model provides reliable meteorological forcing fields for CTMs," I again suggest replacing with "adequate" or similar.

Response to comment 4:

We appreciate the reviewer's suggestion. We agree that the terms "high reliability" and "reliable" are somewhat subjective and may overstate the evaluation results. Therefore, we have revised the relevant descriptions in the manuscript by replacing these expressions with more neutral terms such as "adequacy" and "adequate", which more accurately indicate that the WRF-simulated meteorological fields are sufficient for providing meteorological forcing for CTM simulations.

Comment 5:

Section 2.2, lines 214-215: "While parts of Southwest and Central China exhibited slight underestimation (MB < 20 hPa)", I suggest adding a phrase for context such as error related to unresolved terrain altitudes at model resolution.

Response to comment 5:

We appreciate the reviewer's helpful suggestion. We agree that the spatial variation in surface pressure biases may partly arise from unresolved terrain altitude differences at the model resolution, especially in regions with complex topography. Therefore, we have added this explanation in the revised manuscript to provide additional context for the observed underestimation of surface pressure in parts of Southwest and Central China. The revised sentence is as follows:

(Lines 353-356) *While parts of Southwest and Central China exhibited slight underestimation (MB < 20 hPa), likely associated with unresolved terrain altitude differences at the model resolution, surface pressure was slightly overestimated in Guizhou and Chongqing.*

Comment 6:

Section 3.1, Lines 316-326: "This discrepancy mainly stems from differences in chemical mechanisms design among the models" and "In addition, the EPICC-Model employed the CB6r5 chemical mechanism, which offered more comprehensive representation of BVOC oxidation (especially isoprene) compared to CB6r3 (used in CMAQ) and CB05 (used in CAMx), thereby increasing O3 formation potential." All certainly true – see my comments above about running CAMx with CB05 rather than CB6r5. CB05 is a choice, not the only option in CAMx.

Response to comment 6:

We appreciate the reviewer's insightful comment. We agree that CAMx supports multiple chemical mechanisms, and the selection of CB05 in this study represents one possible configuration among the available options. The objective of this work is to evaluate the performance differences among different CTMs under their selected configurations, rather than to assess the impacts of individual chemical mechanism choices. As mentioned in our previous response, CB05 was retained in this study because it has been widely applied and extensively evaluated in regional air quality simulations over China. We acknowledge that the choice of chemical mechanism may influence model performance, and this factor has been considered when interpreting the differences among model results.

Comment 7:

Section 3.1, Lines 406-408: "CAMx generally underestimated O3 nationwide, which may be associated with the use of the CB05 chemical mechanism and the 14σ vertical configuration adopted in this study." See my comments above. Adding reasons for these selections in the model configuration section would help provide the reader valuable context, rather than seeming to be historical requirements or random choices.

Response to comment 7:

We appreciate the reviewer's valuable comment. We agree that the rationale for the selected CAMx configurations should be provided to avoid the impression that these settings were historical requirements or arbitrary choices. Therefore, we have added a brief explanation in Section 2.1 (CTM configurations) regarding the selection of the CB05 chemical mechanism and the $14\sigma_p$ vertical configuration. These configurations were selected based on their established applications in regional air quality simulations and the balance between simulation performance and computational efficiency. In addition, following the reviewer's suggestion, we have added a sentence in Section 3.1 to clarify that updated gas-phase chemical mechanisms and an increased number of vertical layers may help alleviate the O_3 underestimation, although they would entail higher computational costs. The revised sentences are as follows:

(Lines 246-249) *The CB05 chemical mechanism and $14\sigma_p$ vertical configuration adopted in CAMx have been widely applied in regional air quality simulations, providing a reasonable balance between chemical representation, vertical resolution, and computational efficiency.*

(Lines 614-619) *CAMx generally underestimated O_3 across China, which may reflect the combined effects of its gas-phase chemistry and representation of vertical transportCAMx generally underestimated O3 nationwide, which may be associated with the use of the CB05 chemical mechanism and the 14σ_p vertical configuration adopted in this study. (Ren et al., 2022; Tang et al., 2011). Updated gas-phase chemical mechanisms and an increased number of vertical layers may help alleviate this issue, although they would entail higher computational costs.*

Comment 8:

Section 3.4, Lines 720-721: "For Wuhan and Guangzhou, where peak concentrations persisted, model predictions showed approximately one-day deviations." The observations do not indicate that peak concentrations persisted (not like Beijing), I suggest removing that phrase. Figure 12 does not show much difference between the models except in Guangzhou where CMAQ seemed to perform best and the other 2 models under predicted.

Response to comment 8:

We appreciate the reviewer's careful observation. We agree that the phrase "where peak concentrations persisted" may overstate the observed O_3 variations in Wuhan and Guangzhou. We have removed this description and revised the sentence to more accurately describe the approximately one-day deviations between observations and model predictions during the pollution event. The revised sentences are as follows:

(Lines 1009-1011) *For Wuhan and Guangzhou, model predictions showed approximately one-day deviations from observations, likely due to limited responses to abrupt meteorological changes.*

Technical Corrections:

Be sure to define all acronyms at the time of their first occurrence.
Use consistent past or present verb tense. Many sentences within single paragraphs shift between past and present throughout the manuscript.
Throughout manuscript: Perhaps a better word for "identifying" pollution levels or events is "forecasting".
Section 3.2, Lines 524-525: "As shown in the stacked bar charts of PM2.5 absolute concentrations in Figure 6e-7h", I think the authors mean Figures 6e-6h.
Section 3.3, Line 625: Use subscript for $PM_{2.5}$.
Section 3.1, Line 350: Replace "As shown in Figure 3"with "As shown in Table 3".
Section 3.2, Line 569-571: I suggest rewording to "While the EPICC Model demonstrates relatively lower consistency among species, it maintains better performance in terms of RMSE and NMB."

Response to Technical Corrections:

We appreciate the reviewer's careful suggestions on the language and formatting issues. We have thoroughly checked the manuscript and made the corresponding revisions. Specifically, all acronyms have been defined at their first occurrence, inconsistent verb tenses have been corrected to ensure consistency, and "identifying" has been replaced with "forecasting" where appropriate. In addition, we have corrected the figure citation from "Figure 6e-7h" to "Figures 6e-6h", revised "PM2.5" to "$PM_{2.5}$" with proper subscript formatting, corrected the citation from "Figure 3" to "Table 3", and revised the sentence in Section 3.2 according to the reviewer's suggestion.