**Reviewer #1 (Formal Review for Authors (shown to authors)):**

We fully appreciate the reviewer’s helpful and constructive comments. We are sure that these comments and suggestions will enhance our revised manuscript. Our responses are provided below in the blue font.

Atmospheric chemistry plays a vital role in Earth system models, and incorporating interactive chemistry is crucial for understanding both climate and air quality. The authors implement an efficient transport algorithm, achieving a relatively low computational overhead (~20%) when integrating interactive ozone chemistry. Overall, the manuscript is well-written, and I recommend acceptance after addressing the following comments: 

1. Ozone bias reduction and spatial resolution:   
To address ozone overestimation in low-resolution models, a recent study by Gao et al. (2025: Reducing Long-Standing Surface Ozone Overestimation in Earth System Modeling by High-Resolution Simulation and Dry Deposition Improvement, 17, e2023MS004192) improved spatial resolution to better represent urban-rural emission contrasts and identify VOC- or NOx-sensitive ozone production regimes. They also refined ozone dry deposition by incorporating dynamic leaf area index for stomatal conductance and adjusting cuticular resistance under varying meteorological conditions (e.g., rainy vs. sunny days). These modifications significantly reduced ozone overestimation in polluted regions. The authors should discuss these findings in the context of their own bias reduction approach. 

Given the crucial role atmospheric chemistry plays in the Earth system as the reviewer indicated, the primary goal of the present study is to enable interactive tropospheric gas-phase chemistry (i.e., chemUCI) and link it with other parts of the model in the upcoming E3SM version 3 (E3SMv3) official release. This is the first E3SM incorporation of an interactive tropospheric chemistry mechanism in its official version. Our manuscript as the overview paper, therefore, focuses on the standard atmospheric trace gas metrics and the overall climate impacts of the new chemistry. More in-depth and specific analyses will be presented in follow up papers. Refinement of the urban-rural interface for pollution is an important future topic.

The E3SMv3 code has been finalized. The findings in Gao et al. (2025) are relevant for future E3SM versions. We revised the summary section to include at line 389: “It also enables future E3SM developments to incorporate newer findings, for instance, the ozone dry deposition schemes (e.g., Gao et al., 2025)”.

2. Ozone bias improvement in E3SM-chem:   
The ozone bias improvement in this study is promising. However, the authors use a simplified tropospheric chemistry mechanism (chemUCI) with only 28 advected trace gases (Lines 101-104). Given this simplicity and the coarse grid spacing, how does the model accurately capture VOC-limited and NOx-limited regimes? The substantial ozone bias reduction warrants further explanation.

While the exploration of surface ozone biases is undoubtedly valuable, the suggested analyses regarding the impacts of the chemUCI mechanism, horizontal resolution, and various chemical regimes extend beyond the current paper, as outlined in our response to Question #1. Surface ozone bias is influenced by numerous factors beyond those mentioned, including surface winds and the land surface model. We acknowledge the significance of this topic and consider it a promising avenue for future research within the E3SM framework.

Additionally, the authors attribute high ozone bias in UCI CTM simulations to PBL timing (Lines 277-280), but this argument lacks detailed justification. Given the persistent overestimation in low-resolution models, such a large improvement seems surprising. Comparisons over East Asia-where ozone pollution is a major concern-would strengthen the results. Referencing Gao et al. (2025; please see the comment above) on resolution-dependent biases would also provide valuable context.

The conclusion that the high surface ozone bias in the UCI CTM is linked to the timing of the planetary boundary layer (PBL) development is from Schnell et al. (2015). It is a conclusion from their paper based on the shape of the diel cycle. We have updated our manuscript to include this reference on Line 280, allowing readers to access further details.

Surface ozone concentrations observed at individual sites are typically not representative of the gridbox averages used in model simulations (Schnell et al., 2014, and references therein). To address this discrepancy, we adopted the metric proposed by Schnell et al. (2014), which aggregates site observations into grid-average datasets that are comparable with model outputs. We suspect that the reduced model-observation differences noted by the reviewer are partially attributable to this method of aggregating site observations. However, it is important to emphasize that, even with these metrics, most models still exhibit high biases (Figure 4).

The observational data, as well as the ACCMIP and UCI CTM data presented in Figure 4, are sourced directly from Schnell et al. (2015). The key point we aim to highlight is that E3SM-chem's surface ozone results show reasonable agreement with these observations and outperform many other models. While understanding the causes of high surface ozone bias in models is undoubtedly valuable, it falls outside the scope of this overview paper.

Minor comments:   
1. Line 204-206:   
Comparing ozone budget estimates with prior studies (e.g., Table 9 in Lamarque et al. CAM-chem: description and evaluation of interactive atmospheric chemistry in the Community Earth System Model, Geosci. Model Dev., 5, 369-411, 2012) would bolster confidence in the results. For instance, how do the values in Table 2 of this study align with those in Lamarque et al. or similar works?

Ozone budget numbers in Lamarque et al. 2012 are a bit outdated. We revised our manuscript to explicitly compare with CMIP6 budget terms reported in Griffiths et al. (2021) Table 1. The revised text was inserted on Line 197 and reads: “These results are typical for chemistry-climate models. For example, Griffiths et al. (2021) Table 1 reported CMIP6 1995-2004 multi-model tropospheric ozone budget ranges: burden = 310-387 Tg, surface deposition = 791-1992 Tg/year, chemical production of Ox = 3987-5315 Tg/year, chemical loss of Ox = 3576-4476 Tg/year, net chemical production of Ox = 411-839 Tg/year.”

Griffiths, P. T., Murray, L. T., Zeng, G., Shin, Y. M., Abraham, N. L., Archibald, A. T., Deushi, M., Emmons, L. K., Galbally, I. E., Hassler, B., Horowitz, L. W., Keeble, J., Liu, J., Moeini, O., Naik, V., O'Connor, F. M., Oshima, N., Tarasick, D., Tilmes, S., Turnock, S. T., Wild, O., Young, P. J., and Zanis, P.: Tropospheric ozone in CMIP6 simulations, Atmos. Chem. Phys., 21, 4187–4218, https://doi.org/10.5194/acp-21-4187-2021, 2021

2. Fig. 7: Please briefly discuss the potential climate impacts of stratospheric water vapor biases. Many CMIP6 models lack interactive chemistry; how might these biases affect their projections?

In Figure 9, we evaluated the impact of incorporating interactive chemistry on the overall climate, concluding that E3SM performs well compared to other CMIP6 models. While isolating the specific climate impacts of stratospheric water vapor changes would be valuable, such an analysis aligns more closely with a DAMIP-type study. Conducting the suggested analysis would require significant effort and extensive simulations to effectively isolate the effects of stratospheric water vapor. The E3SM team plans to address this topic in a follow-up paper focused on individual climate forcings in E3SMv3. Other CMIP6 models without interactive stratospheric CH4-H2O chemistry may or may not have similar biases since this depends on how they defined stratospheric H2O, and that is a complication beyond our study.

3. Fig. 12 The 2-m air temperature biases (bottom left) exceed 4 K in several regions. What could explain these large discrepancies?

Panels c and d in Figure 12 reveal that the patterns and magnitudes of 2-m air temperature biases in E3SM remain largely unchanged regardless of the inclusion of interactive chemistry. This indicates that interactive chemistry is not the primary driver of surface air temperature biases.

In the E3SMv2 overview by Golaz et al. (2022), several factors contributing to regional 2-m temperature biases were identified, including model deficiencies in clouds, precipitation, and aerosol effects. Additionally, Lee et al. (2023) found that the summertime warm bias over the central United States in E3SMv2 is linked to a lack of low-level clouds during non-precipitating days, resulting in excessive incoming solar radiation.

Golaz, J.-C., Van Roekel, L. P., Zheng, X., Roberts, A. F., Wolfe, J. D., Lin, W., et al. (2022). The DOE E3SM Model version 2: Overview of the physical model and initial model evaluation. Journal of Advances in Modeling Earth Systems, 14, e2022MS003156. <https://doi.org/10.1029/2022MS003156>

Lee, J. M., C. Tao, W. M. Hannah, S. Xie, and D. C. Bader, 2023: Assessment of Warm and Dry Bias over ARM SGP Site in E3SMv2 and E3SM-MMF. J. Atmos. Sci., 80, 2545–2556, <https://doi.org/10.1175/JAS-D-23-0062.1>.

4. Table 3: Clarify the methodology for calculating CH₄ lifetime. The authors note that lower values during 2010-2014 are driven by tropospheric OH changes (linked to rising O₃, anthropogenic emissions, and H₂O from climate change). Are there established references supporting this interpretation?

As indicated in Table 3 and its note, CH4 lifetime is calculated in the standard, defined method as total burden divided by different loss pathways in the columns. Additionally, we incorporated references to Skeie et al. (2023) and Stevenson et al. (2020) on Line 221 to substantiate the driving factors—namely increased tropospheric ozone (O₃), anthropogenic emissions, and humidity—that contribute to the rise in tropospheric hydroxyl radicals (OH) and, consequently, the reduction in methane (CH₄) lifetime.

Skeie, R.B., Hodnebrog, Ø. & Myhre, G. Trends in atmospheric methane concentrations since 1990 were driven and modified by anthropogenic emissions. Commun Earth Environ 4, 317 (2023). https://doi.org/10.1038/s43247-023-00969-1

Stevenson, D. S., Zhao, A., Naik, V., O'Connor, F. M., Tilmes, S., Zeng, G., Murray, L. T., Collins, W. J., Griffiths, P. T., Shim, S., Horowitz, L. W., Sentman, L. T., and Emmons, L.: Trends in global tropospheric hydroxyl radical and methane lifetime since 1850 from AerChemMIP, Atmos. Chem. Phys., 20, 12905–12920, https://doi.org/10.5194/acp-20-12905-2020, 2020.