Response to Referee #1

General Comments:

This paper presents a modelling study that investigates the impact of the observed vertical aerosol distribution on the simulated photochemistry over Northern China. This paper builds on gaps in the field where few modelling studies using chemical transport models have considered actual observed vertical aerosol distributions when simulating the effects of the aerosol - photolysis interaction. Using combinations of lidar data and radiosonde observations the authors demonstrate that incorporating these into GEOS-Chem can help address the biases in AOD in the model and show the subsequent response on ozone levels and particulate matter. The authors test the sensitivities of aerosol photolysis interactions using numerous scenarios and robustly evaluate the effects of including the observational constraints including looking at impacts of on the atmospheric oxidising capacity and boundary layer effects. They also evaluate the effects in both the winter and summer seasons where the impacts of aerosols on atmospheric chemistry can behave very differently. Overall, the paper is well written and provides a valuable contribution to understanding photochemistry under changing pollutant regimes and the importance of representing the vertical distribution of aerosols in the model as accurately as possible. I recommend publication in ACP after the following minor comments are addressed.

We thank the referee for the constructive comments, and we have addressed them carefully. Please find our response in blue.

Specific Comments:

This paper focuses on the impacts of aerosol optical depth on photochemistry. Whereas the authors provide evaluation of the model for aerosol optical depth (and identify and correct biases) they do not evaluate and benchmark how well it currently captures observed photolysis rates at the observational sites. I appreciate that measured photolysis rates (E.g. JNO_2) may not be available at all sites but if there is data available it would be great if the authors could provide an observational comparison. Due to the potential of data limitations I would not suggest this is needed for publication but think it would greatly enhance the model evaluation if such data was available.

Many thanks for this suggestion, and we agree with the reviewer that a model evaluation against measured photolysis rates will be very helpful.

However, such a comparison during the study period is not available due to data limitations, although we have compared the simulated $J[NO_2]$ with the reconstructed dataset derived from observed data in Figure 3. This dataset was reconstructed by observational $J[NO_2]$, total ultraviolet radiation, and troposphere ultraviolet and visible (TUV) radiation model, and showed a great consistency with observational $J[NO_2]$ at Xianghe station ($R^2 = 0.94$). As demonstrated in Lines 274–276, the revised aerosol vertical distribution improved the underestimation of $J[NO_2]$.

Besides, following Referee #2's suggestion, we have added additional NO_2 validation in Lines 155–161, to further verify the reliability of the NO_2 photolysis simulation.

We also added a discussion to highlight the necessity of including more model evaluations using observed photolysis rates in future studies in Lines 486–488: "Moreover, the model validation with observed photolysis rates should be involved, as the photolysis rate is one of the most direct variables for verifying the simulation of photochemical reactions."

Technical Corrections:

Page 3, line 64: Please remove 'the' between suppress and secondary

Corrected.

Page 3, line 94: This last sentence is not quite clear. Do you mean to investigate the response of photochemistry to observed constraints on vertical aerosol distributions?

Yes. It has been changed to: "to investigate the response of photochemistry to observed constraints on aerosol vertical distributions."

Page 4, line 122: You mention the various schemes used here for boundary layer mixing, dry deposition, wet deposition and emissions but you don't mention the chemical scheme deployed in the model. Please add this here.

We have added the description of the chemical scheme in Lines 124–125: "The standard chemistry simulation with fully coupled ozone-NO_x-hydrocarbon-aerosol chemistry mechanisms was employed in this study."

Page 5, Figure 1: I am finding the red boxes in plots (b) and (c) a little hard to read, would it be possible for these to be made a little bolder and perhaps plotted in black to make them stand out better on the page?

Thanks! We have changed the boxes in Figure 1(b) and (c) using bolder black ones.