Response to Referee #2

The study presents the updated version of the aerosol radiative feedback algorithm in the coupled meteorology-chemistry model WRF-Chem v4.4. The manuscript also describes the current algorithm utilized in the default version of WRF-Chem. A full gas-aerosol chemistry scheme CBMZ-MOSAIC is used to simulate the aerosol radiation feedback for different regions of the world. One domain covers China, and another one covers the Saharan region.

The model simulations with the default and updated algorithms show some differences in the aerosol optical depth and single scattering albedo, in particular for the Saharan region. The authors show better agreement of the model with the AERONET AOD data when the updated aerosol radiative feedback algorithm is used.

The updated algorithm can help to improve the WRF-Chem air quality and meteorological simulations. I recommend publishing the manuscript after addressing the following comments.

Response: We sincerely appreciate your thorough and insightful review of our manuscript. Your comments and suggestions have been invaluable in enhancing the quality and clarity of our work. We have addressed each of your specific comments, as detailed in our point-by-point responses below. We believe these revisions have strengthened our manuscript and hope that they adequately address your concerns.

- ***Lines 235-240: You mention the indirect feedback. Are you referring to semi-direct feedback? I assume your WRF-Chem configuration does not include the aerosol-cloud interactions.***

Response: We appreciate that you point this out and sorry for the confusion. Yes, we refer to semi-direct feedback and we modified our description as: "these effects include not only the direct radiative effect (DRE) of aerosols but also the indirect consequences: the alterations in radiative forcing induced by aerosols can lead to effects on the atmospheric energy balance, which in turn influence other meteorological processes such as the cloud formation and thus further affecting radiation." Besides, our WRF-Chem configuration includes the aerosol-cloud interactions. The aerosols spatial distributions and physical properties can interact with the Morrison 2-momnet microphysics scheme, which we used in WRF-Chem.

Actually, we want to express that the near-surface temperature is influenced not only by direct radiative effect and discuss other possible factors below. The discussion caused some confusion. We now make it clearer in the revised manuscript as: "This difference indicates that the radiative effects of aerosols on near-surface temperature are influenced not only by radiative forcing (direct radiative effect) but also by other factors such as aerosol-cloud interactions, the aerosols heating effects and the radiative effects on the surface radiative fluxes discussed below."

- ***The resolution of your WRF-Chem grid is quite coarse (50km). I'm wondering if high-resolution simulations (e.g. 4-10km) would yield somewhat different results. For instance, anthropogenic pollution can be better simulated by a high-resolution model.***

Response: We appreciate your insightful comment regarding our model resolution and the potential implications of using higher-resolution simulations. Our choice of a 50km grid resolution was based on several considerations: Computational resources: Given the spatial domain and extended time period of our simulations, a 50km resolution allowed us to complete our study within available computational resources; Besides, our primary aim was to investigate the effects of modifications of algorithm on simulating results. Simulating an accurate aerosols distribution is not our main purpose. Therefore, we consider that a 50km resolution is generally adequate for this study.

We acknowledge that higher-resolution simulations (e.g., 4-10km) could indeed yield somewhat different results, particularly for anthropogenic pollution. Potential benefits of higher resolution include: Improved representation of local emissions: Finer grids can better resolve point sources and urban areas; Enhanced simulation of meteorological processes: Higher resolution can better capture local circulations and boundary layer processes that affect pollutant transport and transformation; More accurate terrain representation: This could improve simulations in areas with complex topography and further effect the physical processes of aerosols such as emission, deposition and transport processes.

Given these potential impacts from resolution, we agree that it would be valuable to explore how higher-resolution simulations will improve the simulation results of aerosols distributions. However, our main purpose is to demonstrate the importance of using a spectrally resolved method for calculating aerosol optical properties, rather than to improve the overall model performance of aerosol distributions. We have added a paragraph in the discussion section of our manuscript acknowledging the model resolution's effects: "It's important to note that the primary aim of our study is to demonstrate the importance of using a spectrally resolved method for calculating aerosol optical properties, rather than to improve the overall model performance. Many factors can affect the simulation of meteorological fields and radiative processes beyond the optical properties methods we're investigating in this study. For example, while our study employs a 50km grid resolution, which is suitable for investigating aerosol-radiation interactions, higher-resolution could enhance the simulation of aerosol emission, deposition, and transport processes, potentially leading to a more accurate representation of aerosol distributions and their radiative effects (Feng et, al., 2023; Tan et, al., 2015; Tao et, al., 2020). In addition to model resolution, the calibration factors for aerosol emission rates, the representation of aerosol size distributions, the quality and accuracy of input data, and the selection and implementation of parameterization schemes for various physical processes could all introduce uncertainties and potential impacts on the simulated results."

- ***I recommend adding the satellite AOD data for the evaluation of the model sensitivity simulations. The spatial coverage of the satellite observations would***

greatly complement the sparse AERONET observations used in the model evaluations.

Response: We thank the reviewer for inquiring about the use of other datasets. MODIS satellite AOD is typically available only at 550 nm. For the 'Interpolated' and 'Resolved' methods, the AOD results are similar at 550 nm because both methods use the same calculation approach when the wavelength is the same. While satellite results could cover more regions, the comparison at a single wavelength would not effectively demonstrate the differences between our methods. The multi-wavelength data from AERONET allows us to show these differences more clearly. In the revised manuscript, we add these discussions: "To evaluate the modelling results, multi-spectral aerosol optical depth (AOD) measurements are required, which is critical for this study comparing the "Interpolated" and "Resolved" methods across wavelengths. Therefore, the retrieved total AOD from the AERONET network (Holben et al., 1998). Although satellite AOD products such as from the Moderate Resolution Imaging Spectroradiometer (MODIS) have greater spatial coverage, the number of wavelengths is limited. Comparison at only one or very few wavelengths would not effectively demonstrate the distinctions between the two algorithms examined in this work."

- ***Given the significant impact of the updated algorithm on heating rates over Sahara, it'd be helpful to evaluate the temperature simulations by WRF-Chem. Such an evaluation would help to determine whether the improved AOD and SSA simulations lead to improvement of the meteorological simulations. The authors present some comparisons with the reanalysis data, but comparing directly to the surface stations (e.g. 2m air temperature) would be really informative. To my knowledge, some global models such as GFS don't assimilate the ground-based weather observations.***

Response: Thanks for your great suggestion. While we understand the value of such comparisons, we would like to address this concern and explain our approach:

Focus of the study: The primary aim of our study is to demonstrate the importance of using a spectrally resolved method for calculating aerosol optical properties, rather than to improve the overall model performance. We show that the "Resolved" method can capture complex relationships between aerosols' optical properties and wavelengths that the "Interpolated" method may miss, particularly for dust-dominated regions and at specific wavelengths. Besides, our results demonstrate that the amendment of algorithms can significantly affect the simulation results. While these changes may not necessarily lead to better agreement with observations in all cases, they give the model more potential to improve simulation abilities by more accurately representing the underlying physical processes.

Complexity of model evaluation: It's important to note that many factors can affect the simulation of meteorological fields and aerosol properties beyond the optical properties methods we're investigating such as model resolution, physical algorithms, parameterization schemes, and input data quality. Given this complexity, direct comparisons of the "Resolved" and "Interpolated" methods with observations may not provide a conclusive assessment of whether our modifications improve the model's overall simulation abilities.

We have added further discussions in Section 4 as: "It's important to note that the primary aim of our study is to demonstrate the importance of using a spectrally resolved method for calculating aerosol optical properties, rather than to improve the overall model performance. Many factors can affect the simulation of meteorological fields and radiative processes beyond the optical properties methods we're investigating in this study. For example, while our study employs a 50km grid resolution, which is suitable for investigating aerosol-radiation interactions, higher-resolution could enhance the simulation of aerosol emission, deposition, and transport processes, potentially leading to a more accurate representation of aerosol distributions and their radiative effects (Feng et, al., 2023; Tan et, al., 2015; Tao et, al., 2020). In addition to model resolution, the calibration factors for aerosol emission rates, the representation of aerosol size distributions, the quality and accuracy of input data, and the selection and implementation of parameterization schemes for various physical processes could all introduce uncertainties and potential impacts on the simulated results. Given this complexity, direct comparisons of the "Resolved" and "Interpolated" methods with observations may not provide a conclusive assessment of whether our modifications improve the model's overall simulation abilities. Therefore, we didn't evaluate the model's simulation results of meteorological fields from two methods by comparing with more observation results other than the ERA5 reanalysis dataset. Our results show that the "Resolved" method can capture complex relationships between aerosols' optical properties and wavelengths that the "Interpolated" method may miss, particularly for dust-dominated regions and at specific wavelengths where water contents have a significant larger absorption than other wavelengths. Besides, our results demonstrate that the amendment of algorithms can significantly affect the simulation results of meteorological fields. While these changes may not necessarily lead to better agreement with observations in all cases, they give the model more potential to improve simulation abilities by more accurately representing the underlying physical processes."

Reference

Feng, J., Zhao, C., Du, Q., Xu, M., Gu, J., Hu, Z., and Chen, Y.: Simulating Atmospheric Dust With a Global Variable-Resolution Model: Model Description and Impacts of Mesh Refinement, Journal of Advances in Modeling Earth Systems, 15, e2023MS003636, https://doi.org/10.1029/2023MS003636, 2023.

Tan, J., Zhang, Y., Ma, W., Yu, Q., Wang, J., and Chen, L.: Impact of spatial resolution on air quality simulation: A case study in a highly industrialized area in Shanghai, China, Atmospheric Pollution Research, 6, 322–333, https://doi.org/10.5094/APR.2015.036, 2015.

Tao, H., Xing, J., Zhou, H., Pleim, J., Ran, L., Chang, X., Wang, S., Chen, F., Zheng, H., and Li, J.: Impacts of improved modeling resolution on the simulation of meteorology, air quality, and human exposure to PM2.5, O3 in Beijing, China, Journal of Cleaner Production, 243, 118574, https://doi.org/10.1016/j.jclepro.2019.118574, 2020.