

We would like to thank the referees for their careful reading of our manuscript. We are most grateful for the comments, constructive criticism and very useful suggestions received on how to improve the paper. Please find attached our detailed answers to the questions and a new version of the paper, which we hope satisfactorily to address the points raised during the discussion. The referee's comments are presented in black, and our responses are in blue.

Reply to Community Comments: CC 1

1. The literature review appears incomplete regarding previous WRF-Chem/GOCART dust studies over the Middle East. Ukhov et al. (2020, ACP) performed a multi-year, high-resolution WRF-Chem evaluation using AERONET, MODIS, MAIAC, MERRA-2, and CAMS, including AOD, aerosol size distributions, and surface PM. Ukhov et al. (2021, GMD) further documented important corrections and improvements to the WRF-Chem/GOCART dust implementation. These studies are directly relevant to the present model configuration and evaluation and should be referenced and discussed. Their omission is surprising given the strong overlap with the present work.

Reply: We thank the reviewer for pointing out these relevant publications. We have revised our literature review (Sec. 1) to include these studies.

2. Authors state that "A comprehensive evaluation of the dust scheme in WRF-Chem over extended periods is lacking in the literature." This statement should be qualified. Previous multi-year WRF-Chem dust evaluations exist, including over the Middle East (see Comment 1). The broader dust-belt domain and systematic dust-scheme/LSM comparison may be novel, but the current statement understates previous work.

Reply: We thank the reviewer for bringing this point to attention. We have revised the statement to: *"A comprehensive evaluation of multiple dust emission schemes coupled with different land surface models in WRF-Chem over an extended period and across the broad domain remains limited in the literature..."*

3. Use of MIDAS is reasonable because it provides dust-specific optical depth rather than total MODIS AOD. However, MIDAS is not purely observational because its dust fraction is derived from MERRA-2. The authors should discuss how this dependence may affect the evaluation and the derived scaling factors. Comparison with an additional independent product would strengthen the analysis.

Reply: We thank you for this recommendation, which is also noted by the anonymous reviewers. We have taken this into account and have now extended the discussion (Sec. 5) to include these uncertainties and consequent dependencies of the derived scale factors:

“The evaluation of our WRF-Chem configurations with MIDAS is subject to several uncertainties as it is based on MODIS-Aqua AOD and MERRA-2 dust-to-total AOD ratio, whose individual biases can propagate into the derived DOD ((Gkikas et al., 2021)). Although MERRA-2 assimilates observed total AOD, its aerosol speciation is not directly constrained and may depend on underlying aerosol model and associated parameterisations ((Buchard et al., 2017)). Nevertheless, the MIDAS DOD product has been evaluated against AERONET observations under dust-dominated conditions ((Gkikas et al., 2021)), and supporting its suitability as a reference dataset for DOD evaluation. A further consideration is that the MERRA-2 aerosols fields used to derive MIDAS are generated using the GOCART aerosol module ((Randles et al., 2017)) and this overlap with the GOCART as well as the AFWA (which is based on GOCART) modules of the WRF-Chem model can contribute to the closer agreement between the modelled and MIDAS data. The scaling factors derived from MIDAS therefore inherit uncertainties associated with the dataset.”

We also conduct an independent evaluation against AERONET station network measurements.

4. Authors define (s_p) as "the fraction for each size section" but do not provide the numerical values used. These values should be explicitly reported for reproducibility. Dust size partitioning can substantially affect AOD, transport, deposition, and surface PM, and therefore may also influence the derived scaling factors

Reply: The numerical values for the fraction of each size section are as follows :

Bin 1: 0.1–1.0 μm (effective radius: 0.73 μm),

Bin 2: 1.0–1.8 μm (effective radius: 1.4 μm),

Bin 3: 1.8–3.0 μm (effective radius: 2.4 μm),

Bin 4: 3.0–6.0 μm (effective radius: 4.5 μm),

and Bin 5: 6.0–10.0 μm (effective radius: 8.0 μm).

We have also included this in the manuscript in Sect. 2.1.

5. The manuscript sometimes appears to equate better AOD agreement with a better dust emission scheme. However, AOD depends not only on dust emission flux but also on particle-size distribution, optical properties, transport, vertical distribution, and deposition. Better agreement with observed AOD therefore does not necessarily imply a more physically accurate emission flux. This distinction should be made clearer.

Reply: Thank you for the comment. We have revised the discussion to include:

“However, since AOD is also influenced by particle size distribution, transport, vertical distribution and deposition, closer agreement with observed AOD cannot be directly

interpreted as more accurate dust emissions rather as overall model performance.” in (Sect. 5) to clarify the distinction.

6. The 50 km horizontal resolution appears too coarse for evaluating regional dust-emission schemes, particularly over heterogeneous source regions such as the Arabian Peninsula. This concern is supported by 10km sensitivity experiment, where the resolution-related AOD variability reaches local values exceeding 60–80% over parts of the Middle East, and Arabian Peninsula. However, the 10km experiment covers only 24 days and uses only one LSM. Therefore, this limited sensitivity experiment does not seem sufficient to support the broad conclusion that the derived scaling factors are resolution-independent and transferable to higher-resolution simulations. This conclusion should be qualified.

Reply: We agree with the referee that the 24-day, 10-km sensitivity experiment, based on a single LSM, is not sufficient to provide a comprehensive assessment of the resolution dependence of the derived scaling factors. While computational constraints prevent us from performing year-long simulations at higher resolution, the sensitivity experiment provides an indication of the potential effects of resolution. We have therefore revised the manuscript to qualify our conclusions to make clear that the scaling factors are not unequivocally resolution-independent or directly transferable to higher-resolution simulations. We now explicitly acknowledge that further multi-season and multi-LSM high-resolution simulations would be required to robustly assess their resolution dependence and transferability.

“These results serve as indicative, and further multi-season and multi-LSM high-resolution simulations would be required to robustly assess the resolution dependence and transferability of scale factors.”

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