# Evaluating simulations of ship tracks in a km-scale model

Author Response

*Anna Tippett, Paul R. Field, and Edward Gryspeerdt*

We thank both the reviewer and the editor for their helpful comments and engagement throughout this review process. Following the most recent round of comments on the 3rd revision of the manuscript, we agree with the reviewer that any evaluation of the model representation of aerosol microphysics within our simulations, and the direct impact of aerosol on clouds, is not possible due to the simplified aerosol configuration. As such, we reframe the study's true objective as the evaluation of the model's representation of LWP adjustments to an Nd perturbation.

We hope that this alleviates concerns regarding the use of the simplified aerosol configuration, as no claims are made regarding the aerosol-microphysics other than the findings of Section 3.1, which relies on offline parcel model calculations. Below, we summarise the changes made to remove any ambiguity regarding the scope of this study and further clarify the limitations introduced.

Small changes are not listed here but can be found in the diff.tex. Larger modifications are detailed below. Line numbers are from the diff.tex file.

| | Comment | Response |
|---|---|---|
| **1** | Clarify and narrow claims: explicitly state that this is not an aerosol validation study. Remove or soften any statements implying that realistic Nd implies realistic aerosol representation. For example, statements/responses such as *"If our background cloud droplet number concentrations are accurate, then our simplified aerosol configuration is sufficient for the purposes of this study"* should be removed or reformulated. Such reasoning is at the core of the reviewer's concern and is unlikely to be persuasive. | Throughout the manuscript we have made numerous modifications such that the aims of the manuscript are clear. Specifically, instead of more generally discussing model representation of "aerosol-cloud interactions", we clarify that we only evaluate model representation of "cloud adjustments". <br><br> We do not modify the title, however, since the findings of Section 3.1 regarding the activation of aerosol still remain important, and do not directly relate to the LWP adjustment. We believe that changing the title of the paper to more clearly discuss evaluation of "adjustments" would not encompass the results about the activation scheme. |

**Changes made**

- Modifications to the abstract to clarify aims with regards to cloud adjustments
- Many modifications have been made to the introduction and throughout to ensure discussion of cloud adjustments is clear. This consists of changing any references of model representation of "aerosol perturbations" to discussion of "cloud adjustments". See diff.tex for more details, since only the larger modifications are listed below.
- **Methods**
  - Line 98: add "This allows us to evaluate the model representation of the cloud adjustments to a Nd perturbation. Crucially, we do not investigate the model representation of the aerosol microphysics, and are more

concerned with the subsequent cloud adjustments after an initial Nd perturbation is applied."

- o Line 207: add "As a result of this simplified aerosol configuration, our only discussion of aerosol-microphysics concerns how the order of magnitude of the injected ship aerosol influences the activation scheme, and relies mainly on offline calculations. Subsequent investigations therefore consider only the model's representation of cloud adjustments to a droplet number perturbation, without evaluating aerosol microphysics or aerosol realism. Future work that increases the level of complexity and considers aerosol properties through to cloud adjustments within more realistic aerosol configurations would be valuable. Nevertheless, this study is intended as a first step toward understanding model representation of cloud adjustments within ship tracks in this context."

- **Results**
  - o Line 337: add "...however acknowledge that this undermines any ability to make claims relating to the injected aerosol number concentration. As such, we investigate the model representation of the cloud adjustments (specifically LWP adjustments) subsequent to the simulated Nd perturbation, which is of the correct magnitude as established in this section"
  - o Line 376: add "...and the limitations of our simplified aerosol configuration are discussed in Section 4.1.2. Due to simplifications in the composition of aerosol field, we do not evaluate the model representation of model microphysics and consider mainly the LWP adjustment to the ship Nd perturbation"

- Line 390: "~~Before 15 hours, the modelled background Nd is within 15cm-3 of the MODIS background, indicating that the simplified aerosol configuration reproduces the background Nd to sufficient accuracy for this work~~. Obtaining similar Nd values inside the track, and in the background is important for investigations into how the LWP adjusts to the ship induced changes in Nd, and the lifetime of the response, which is discussed further in the following section."

- **Discussion**
    - Line 545: add "Crucially, the aims of this work are to investigate LWP adjustments to Nd perturbations inside ship tracks, which are applied in a more realistic method to previous work by using aerosol perturbations at real ship locations. As such, no conclusions about the model representation of the aerosol microphysics can be made. The emissions from the ships are not what the actual ships emitted, and are constant across all 5 ships. Furthermore, the emissions are then tuned to reproduce realistic Nd values inside the ship track, since the activation scheme is found to be unsuitable. Then, the subsequent adjustments in LWP (which are dependent on the absolute Nd value) are investigated."

| | Comment | Response |
|---|---|---|
| 2 | Strengthen the limitations discussion: clearly articulate the implications of simplified aerosol treatment and short spin-up, including what conclusions cannot be drawn. | In light of this new framing of the study, and the latest comments from the reviewer, our limitations discussion has been modified to clearly state the implications of the simplified aerosol configuration, and statements have been added throughout to make clear which conclusions can be drawn from our results. |
| | | **Changes made** |

- Line 534: add "The initialisation from solely accumulation-mode aerosol may also lead to an inaccurate representation of aerosol surface area, which in turn can affect vapour sinks through condensation as well as rates of new particle formation. In addition, the absence of an Aitken mode removes a pathway for particle growth and may result in an underestimation of cloud condensation nuclei (CCN) concentrations. Since the simulations span only 48 hours, there is insufficient time for the aerosol population to evolve toward a more realistic size distribution, despite background emissions into other modes."
- Line 539: add "Despite this, Grosvenor et al., 2017 use a similar initialisation from a uniform field of accumulation mode in CASIM, and find that the resultant Nd is approximately as seen in observations. Similarly, in our simulations…"

| | Comment | Response |
|---|---|---|
| 3 | Provide a constrained aerosol consistency check: include a comparison of simulated aerosol optical depth against a satellite product such as MODIS during and after spin-up. Even a domain-mean or regional comparison would provide a useful contextual constraint without requiring additional long simulations. | Since satellite derived AOD from MODIS cannot be obtained in cloudy scenes, we rely on evaluation against CAMS reanalysis. Figure S3 has been modified to compare simulated AOD against CAMS AOD in the domain-wide mean for 2018-07-12.

This figure demonstrates that whilst the simplified aerosol configuration contains only accumulation mode aerosol, the AOD is not completely unconstrained and looks reasonable compared to CAMS. This does not mean that the aerosol microphysics will be entirely realistic, since the composition is not realistic, however provides a contextual constraint. |

**Changes made**

- Line 520: "An evaluation of the sulphate mass mixing ratio and the simulated AOD against CAMS reanalysis are provided in the Supplement (Fig. S3) and are found to only have small spatial

Reviewer #2 comment: "A full aerosol evaluation is likely not possible, due to a lack of coincident measurements, so the reference to CAMS may be necessary. Note that while the CAMS aerosol scheme benefits from data assimilation, it is a simple single

moment (mass) scheme and can't be thought of as a substitute for measurements.

In the new supplemental material (Fig. S3) a qualitative comparison of sulfate mass distribution is used to suggest the 200 cm-3 number concentration is valid, however this is not a validating comparison. Mass concentrations can remain steady even as number concentrations vary.

The CAMS AOD presented in Fig. S4 could prove to be useful, however without seeing the GLOMAP AOD alongside there is little to be gained from the figure.

The fallback position of the authors is that if simulated Nd is adequate, then the underlying aerosol is also adequate. For the reasons noted in the previous section, I don't agree with this statement."

differences. However, neglecting other aerosol components (which are significant; Fig. S4) might impact the formation of cloud droplets and the initiation of precipitation in this work (although we find that the precipitation representation is reasonable; Fig. 5) Whilst initialising from a single aerosol mode appears to reproduce the AOD from CAMS, this does not ensure accurate representation of the size distribution which could, in turn, influence the simulated response to additional aerosol."

### *Reviewer #2 Minor Comments*

| | Comment | Response |
|---|---|---|
| 1 | Please be more specific when referring to 'aerosol concentrations'. e.g. aerosol mass concentrations; aerosol number concentrations, CCN number concentrations, etc. | Thank you to the reviewer for this point. We have made modifications to the manuscript to ensure that every reference to an aerosol concentration is now clearly referring to either a number or mass concentration (or in some cases both). |
| | | **Changes made** |

- See diff.tex for changes throughout the manuscript.