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# *Interactive comment on* "Evaluating the effects of microphysical complexity in idealised simulations of trade wind cumulus using the Factorial Method" *by* C. Dearden et al.

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On behalf of all the authors, the first author would like to take the opportunity to thank the reviewer for their careful consideration of the manuscript and for the insightful comments and suggestions which help to improve the quality of the manuscript.

Response to general comments

Two main points are raised by the reviewer. The first is concerned with the question of dynamical feedbacks, and the authors are asked to include a discussion of how such feedbacks may modify the sensitivities shown by each of the microphysics schemes. The authors feel that whilst such feedbacks are potentially very important, it is perhaps not the goal of the paper to evaluate the impact of such feedbacks, but rather to demonstrate how, for a given scenario, the Factorial Method can be used as a tool for comparing the sensitivities of microphysics schemes of different complexities. However, the authors have made an attempt to comment on the potential impact of feedback effects in the summary and discussions section. In light of the comments, the authors feel it would be of benefit to highlight the caveat of no feedbacks/entrainment earlier in the manuscript, and so propose replacing the sentence beginning on line 29 of page 23500 and ending on line 3 of page 23501 with the following:

"The sensitivity of the bulk schemes can be quantified and compared to that of the bin scheme such that it will be possible to isolate those regimes where the additional microphysical complexity is warranted. It is important to note that the 1-D framework used in this study does not permit feedbacks between microphysics and dynamics. The simplicity of the driver model is by design; whilst the importance of feedback effects are recognised, they also make it difficult to isolate differences that arise purely from the treatment of microphysics and potentially other factors (such as the numerical handling of advection), and so an idealised study in the absence of feedbacks is beneficial in terms of identifying and understanding the potential limitations of simpler bulk parameterizations. In addition, the simplicity of the driver model allows for a greater number of sensitivity tests to be performed compared to 3-D simulations due to the reduced computational burden. This provides the justification for the simplified approach adopted here, and the FM is presented as a tool to enable such a comparison of microphysics schemes to be made."

The authors also propose to modify the sentence in lines 6-9 of page 23501 with the following:

"The results from each microphysics scheme are analysed and compared in Sect. 4, and the potential implications of these findings are addressed in Sect. 5, including a discussion of how feedbacks between microphysics and dynamics may potentially modify the sensitivities shown."



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Interactive Discussion

Discussion Paper

It is suggested that Section 5 of the revised manuscript (summary and discussion section) will be updated with the following, after the first sentence of the final paragraph:

" A big caveat in producing these conclusions is the absence of any entrainment effects in the results shown. The 1-D framework does not account for entrainment mixing within the cloud, and in reality, the effect of entrainment mixing could to some extent counteract the change in temperature due to vertical advection. The study by Jiang et al (2006) used a 3-D LES modelling approach to compare the lifetime of polluted cumulus clouds to those of clean cumulus clouds when entrainment is allowed to occur. The results suggest the overall lifetime of both the polluted and clean clouds are statistically similar, and propose an evaporation-entrainment feedback mechanism which acts to dilute polluted clouds (i.e. reduce liquid water content) and therefore reduce the overall sensitivity of warm shallow cumuli to changes in aerosol concentration. Based on this result, it is possible that the sensitivities shown to increasing CCN concentrations in this study could be damped if the simulations were performed in 3-D. "

The second point raised concerns the focus on accumulated precipitation as the sole metric upon which the Factorial Method (FM) analysis is based. This is a fair point and indeed the original intention was to consider an additional metric such as cloud liquid water path as suggested in Dearden (2009). Ultimately this was omitted from the submitted manuscript in the interests of conciseness, as it was felt that the results based solely on the precipitation metric were of sufficient interest on their own.

Response to specific comments

1) Added relevant citation (Wang and McFarquhar, 2008)

2) In regards the following sentence "...has become feasible to include indirect effects on warm convective clouds..." The first author was referring to GCM cloud parameterizations here. Even though AIEs in such schemes are highly parameterized or even imposed as the reviewer says, in recent years some of the latest convection schemes to emerge have contained sufficient microphysical detail to consider single-moment treat-



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ments of cloud liquid and rain for example, where cloud droplet number concentration is diagnosed as a function of the aerosol mass, and rain mass is determined based on a parameterized autoconversion rate (e.g. Graf et al 2009), and so a consideration of microphysical complexity as is presented in the paper may well be of relevance to this 'next-generation' of convection scheme.

3) The recommended reference of Stein and Alpert (JAS 1993) in relation to the FM has been included in the manuscript

4) Details of the KK process rates, p.23503. The manuscript has been updated so that it now reads: "The microphysical process rates in the KK scheme are formulated via multiple nonlinear regression of simulated spectra from LES simulations of marine boundary layer clouds, and so is considered to be an appropriate choice for this study."

5) On the issue of why the study assumes mu=0 for rain: The assumption that mu=0 is made in the Morrison scheme and arises due to the use of the Marshall-Palmer distribution (1948) to describe the rain size distribution, which by definition assumes mu=0. To allow the scheme to predict or diagnose the shape parameter for rain would require a considerable re-write of the Morrison code which is beyond the scope of the study.

6) The distinction between cloud and rain categories has been made more explicit in the manuscript ("liquid" now replaced with "cloud liquid water").

7) Rationale behind 1/w timescale: This was made simply so that changes in the strength of the updraft do not result in changes in cloud depth, i.e. the maximum extent the column is lifted vertically is the same even when the strength of the updraft increases. A consistent cloud base and cloud top height were required in order to conduct a rigorous analysis of the effect of different factors on precipitation. The choice of t2=1200/w1 comes from the default setting for the warm1 case as specified in Shipway & Hill (2010), also available in the KiD documentation (Shipway 2010, Met Office Technical Note No. 549, or from http://appconv.metoffice.com/microphysics/index.shtml),



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where w1=2m/s and t2=600s.

8) The reference to Dearden (2009) has been included in section 3.2, particularly in relation to the relative contributions (the 2nd reviewer also picked up on this and has requested some additional detail in the manuscript regarding how the relative contributions are calculated)

9) Although the manner of denoting the temperature profile is not dimensionally consistent with the other two parameters, the authors felt that this was a neat and more concise way of distinguishing between changes in the value of the temperature factor.

10) On the issue of using a 40 micron diameter threshold for rain: This is an error in the manuscript since the bulk models actually use a 50 micron diameter threshold for rain, as defined by the KK autoconversion scheme (Khairoutdinov and Kogan, 2000). The figures that diagnose rain mass for the bin scheme (figures 4 and 5) will be replotted for the revised manuscript to ensure that they use this same threshold size (the conclusion that the ACPIM bin scheme produces a larger rain mass relative to the bulk schemes is unaffected).

11) No response required (although it should be mentioned that the 3rd reviewer has made some points about Fig. 5 which will be addressed separately);

12) See comment 8;

13) Page 23514: The reviewer is correct that the lack of sensitivity at large vertical velocities is down to the fact that all CCN are activated at some threshold value; the manuscript has been updated on page 23514 with the additional sentence: “This is a consequence of the fact that, towards larger vertical velocities, the droplet number concentrations converge in the bulk schemes, thus producing very similar sensitivities”.

14) The statements about balance between complexity and cost: the caveat of no dynamical feedbacks will be stressed when making these points in the revised manuscript.



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15) In response to the reviewer comment that a single-bin microphysics solution cannot be thought of as truth or used as a baseline for verification of bulk models: This may be true, but to confirm this would require direct comparison of the ACPIM model with other bin schemes which is beyond the scope of the manuscript. Instead the manuscript suggests possible causes of potential differences in sensitivities between bin schemes, which will be explored separately in future work on the subject.

16) The thinking behind putting the ACPIM bin microphysics into a 3-D LES model is to eventually allow for an investigation of the effects of entrainment mixing in future studies, which can only really be achieved in 3-D, to help evaluate how such mixing would affect the sensitivities shown here. However, it has been proposed that this sentence be replaced in favour of a discussion of the potential influence of entrainment effects (see response to general comments).

Technical comments

The authors will strive to improve the layout and labels of the multi-panel figures in the final manuscript to allow easier readability.

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