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Atmospheric Chemistry and Physics Discussions

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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The authors would like to thank the reviewer for taking the time to consider the manuscript and for making the relevant suggestions and comments.

Response to major points

1. The authors are asked to provide a motivation for the choice of parameters that are varied in the paper, and also for those that are kept fixed. Although the use of the 1-D framework does present some limitations such as the absence of feedbacks between microphysics and dynamics, the authors would like to reiterate that the main motivation for the paper is to present the use of the Factorial Method as a tool for assessing the

sensitivities of different microphysics schemes, for which the 1-D framework provides a suitable demonstration. The three factors that are allowed to vary are the CCN concentration, temperature profile, and vertical velocity. The motivation for exploring the sensitivity to CCN concentration is to understand how different representations of CCN in the schemes (i.e. different levels of complexity) can impact on cloud droplet number concentrations and hence precipitation rates. As for changing the temperature, by maintaining a constant relative humidity during temperature changes it is possible to explore the impact of LWP on precipitation rates. Cooling the temperature by 2degC in the model shows a reduction in LWP of around 10%. Finally the vertical velocity field is varied to explore the relationship between updraft strength and the number of droplets activated, and how this dependency differs between schemes that have different methods of droplet activation. Using the Factorial Method it is possible to quantify which of these factors is dominant in terms of suppressing precipitation for a given set of values, and more over it also allows for a consideration of the potential interactions between these factors. In terms of parameters that are fixed, one of the assumptions in the modelling framework is that increasing the magnitude of the vertical velocity does not alter the cloud depth. In reality an increase in updraught strength would result in more activation of droplets at cloud base, but also an increase in cloud depth and therefore an increase in liquid water path. The increase in liquid water path would lead to an increase in precipitation and therefore mask the effect of the change in droplet number. Thus it was decided that the maximum extent that the column is lifted should be the same regardless of the updraft speed used, in order to examine the ability of each scheme to represent the 1st and 2nd indirect effects in isolation. The authors responses to reviewer #1 (general comments) also discuss some of the issues surrounding the lack of dynamical feedbacks; some speculations are made as to how the sensitivities presented in the paper may change if feedback processes are allowed to occur. This discussion also may be of interest to the reviewer.

2. The reviewer has requested some additional detail with regard the configuration of the bulk scheme; this extra information will be included in the revised manuscript.

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Accretion in the bulk scheme is based on the parameterization of Khairoutdinov and Kogan (2000, MWR) for consistency with the autoconversion scheme. Self-collection of rain drops is also accounted for, and is based on the scheme used in Seifert and Beheng (2001). The differences in sensitivity to temperature and CCN as seen in the manuscript are stated as being attributable to differences in evaporation below cloud base, and the reviewer asks the question whether this can be due to differences in collection efficiencies. Indeed it is believed that the main reason for the apparent reduction in evaporation in the ACPIM bin scheme relative to the bulk schemes is a consequence of the larger drop size in ACPIM caused by the increased efficiency of collection. A direct comparison of the evaporation rates in the subcloud layer is not possible with the current set of results because the evaporation rate is not yet available as a diagnostic in the ACPIM model. The authors would argue that a more detailed comparison of the evaporation rates is not the main point of the paper, but rather to present the Factorial Method as a tool for comparing the sensitivities of different schemes as pointed out in the response to major comment #1; the authors would like to keep the manuscript as concise as possible so as not to distract the reader from the main purpose of the paper. The authors do suggest in the summary and discussion section that a consideration of the effects of collection efficiencies should be addressed in future work as a potential source of difference between bin schemes. Finally, the authors believe that changing the autoconversion and/or accretion rates would have a significant impact on precipitation rates in the bulk schemes; indeed, this has been shown to be the case in a separate study by Shipway & Hill (2010).

3. The size threshold for rain: The reviewer is correct that the KK scheme uses a separation radius of 25 microns. Indeed this was the value used in the bulk simulations and so the statement that a 40 micron diameter was used is a mistake and will need to be corrected in the revised manuscript. The plots that show rain mass from the ACPIM bin scheme will be re-plotted so as to use the same size threshold for rain to match the bulk schemes (the conclusion that ACPIM produces a larger rain mass is unaffected).

4. The shape parameter for rain is diagnosed in the ACPIM model based on a given diagnostic size threshold for rain. For all drops larger than the specified size, the shape parameter is then calculated using moment-conserving fits based on the assumption of a gamma distribution. By considering analytic expressions for the zeroth, first and second moments of a gamma distribution, it is possible to solve for mu where the required unknowns (i.e. the moments themselves) are calculated from the model microphysics. If the reviewer believes it would be of benefit, a complete mathematical derivation for calculating mu based on the method of moment-conserving fits can be included in an appendix in the revised manuscript.

The plot in figure 5 was constructed so that values of mu larger than 30 were not considered, as the precipitation flux was found to be small above this threshold value. On reflection this threshold value may be too high as it leads to the apparent discontinuities at the onset of rain formation; a slightly smaller threshold will be considered for the revised manuscript as it may help to remove such discontinuities.

Response to minor points

5. On the reason why liquid water content peaks near cloud base: This is a consequence of the fact that the whole column is lifted in response to the vertical velocity field, where at a given timestep the applied vertical velocity is the same at every gridpoint. The relative humidity reaches a peak at around 750m; at grid points above this height, the relative humidity begins to decrease such that the amount of water vapour available for condensation is reduced, leading to a slight reduction in liquid water content with height. Whilst this is not necessarily consistent with observations of real cumulus clouds, the chosen profile provides a suitable basis for comparison of different microphysics schemes using the Factorial Method. Also, the reason why LWP doesn't decrease in figure 3 towards the end of the simulations is partly due to the absence of any entrainment effects in the 1-D column framework. In figure 3 the only processes that are allowed to occur are condensation and evaporation, which happen as a result of the advection of water vapour. When the applied vertical velocity field reduces to

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zero, neither condensation or evaporation can occur and so the condensed water just lingers.

Other minor points that require responses:

8.'warm convection' = single phase liquid convective cloud, i.e. no ice present.

11.Sentence changed to read as follows: 'bulk schemes typically assume a functional form of the hydrometeor size distribution."

14.The 1-m scheme still assumes a gamma function for the liquid droplet size distribution, and the rate of change of rain mass due to autoconversion is a function of both the cloud liquid mass and cloud droplet number (i.e. equation 29 in Khairoutdinov and Kogan 2000, MWR), hence the need to specify a value for the droplet number concentration in the 1-m scheme.

The authors are happy with the suggestions made by the author regarding the other minor points raised, and will endeavour to include these in the revised manuscript.

Interactive comment on Atmos. Chem. Phys. Discuss., 10, 23497, 2010.