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Interactive comment on "Parameterizing microphysical effects on variances and covariances of moisture and heat content using a multivariate PDF" *by* Brian M. Griffin and Vincent E. Larson

Brian M. Griffin and Vincent E. Larson

bmg2@uwm.edu

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Response to Anonymous Referee #3

In this response to the reviewer's comments, the reviewer's comments are italicized, and our responses are in roman font.

This paper formulates relations for the effects of microphysical terms on turbulence variance and correlations using a multivariate PDF.

Thank you for your review.

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Discussion paper

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Overall, I found the introductory, overview, and methodology sections to be quite well written while providing a clear motivation for the work. However, I felt the results section seemed incomplete and could be expanded upon a bit to make for a more convincing and satisfying read. Please see the below list on topics I would recommend be addressed before publication could be considered.

More results have been added to the paper, as per the reviewer's suggestions below. The main result of the paper remains the formulas in the Appendix and Supplement that integrate over the PDF, and their implementation in code. These formulas are new, non-trivial to derive, and necessary for checking the convergence of numerical methods of obtaining these terms.

1) How do the mean state fields compare between LES and CLUBB with the new parameterization? Can it adequately simulate the thermodynamic and cloud structure?

Yes, CLUBB can adequately simulate the mean state fields. The revised manuscript now includes a new figure that shows mean state fields that are relevant to and influenced by the microphysical covariance terms.

2) In relation to the above point, what is the effect of the new parameterization on the simulated cloud field? i.e. How does the new version of CLUBB compare to the control version of CLUBB? Providing this information will make the paper stronger by giving the reader a sense of the potential benefits of the new parameterization rather than just showing that the budget terms sort of match up.

To assess the effects of the microphysical covariance terms, we have performed a sensitivity study in which those terms are shut off. A new section has been added to the manuscript in order to describe that sensitivity study. It turns out that, in the budgets, other terms compensate for the omission of the microphysical covariance terms, and the mean fields are significantly changed. In short, when the damping from the microphysical covariance terms is removed, the solution becomes overly vigorous.

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3) Only one case is presented here. Oftentimes this is a warning sign that cherry-picking of the results or over-tuning of one case was the result. It would be nice if the authors somehow address this concern. Have the authors tested their parameterization on a stratocumulus over cumulus type of case?

Unfortunately, we do not have a precipitating stratocumulus-over-cumulus case. However, the revised manuscript now includes plots from the DYCOMSII-RF02 drizzling stratocumulus case. In that case, the microphysical covariance terms are small in both the LES and in CLUBB. It is an informative null case that indicates that CLUBB asymptotes to a reasonable solution in the stratocumulus limit.

4) Overall, the budgets from CLUBB reasonably match LES, although there are some instances where there are significant differences. I feel the authors brush this aside by saying improving these are "out of the scope" of the current work. I feel at minimum, a discussion should be included pertaining to potential reasons for these deficiencies and how improvements could be beneficial for an overall improved simulation of clouds (related to points 1 and 2).

As discussed in the response to reviewer 2, the main error in the microphysical terms is that they extend throughout the cloud layer, rather than being confined to the upper half of the cloud layer, as in LES. The revised version of the manuscript provides the following explanation:

"However, in CLUBB, the range of altitudes where the microphysics budget terms have significant values is shifted lower than in SAM LES. This occurs because $\overline{r_r}$ peaks at a lower altitude in CLUBB than in SAM LES. The lower-altitude peak in rain, in turn, occurs because there is too much evaporation near cloud top, as shown in Fig. 7a of Griffin and Larson (2016). As noted there, the excessive evaporation is caused by an excessively long-tailed marginal subgrid PDF of saturation deficit, which extends to unrealistically dry values. See Griffin and Larson (2016) for more details. The excessive evaporation near cloud top also causes a similar problem in the microphysical terms in

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the other budgets presented below."

References

Griffin, B. M. and V. E. Larson, 2016: A new subgrid-scale representation of hydrometeor fields using a multivariate PDF. *Geosci. Model Dev.*, **9**, 2031–2053.

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