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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

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Response to Anonymous Referee #2

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

The authors compare an LES simulation to a single-column simulation with a model based on higher-order closure relations (CLUBB). Closure relations for the effects of microphysics on turbulent correlations are derived by integrating a simple microphysical model over assumed distribution functions for the fluctuating quantities.

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Thank you for your review.

The main use of this kind of comparison would be to improve the CLUBB model.

As stated in the original version of the manuscript, “A primary purpose of this paper is to perform those integrals analytically and to implement the resulting formulas in a particular PDF parameterization, the Cloud Layers Unified By Binormals (CLUBB) model." Performing the integrals involved considerable labor (see the Supplement), and, in our view, the resulting expressions and corresponding implementation in code are a substantial contribution in their own right. They are new, and they provide a benchmark solution for checking the convergence and accuracy of numerical methods for these terms.

The main use of comparing CLUBB results to LES is to give the reader an illustration of the size of the errors in the new microphysical covariance terms in a simple simulation, namely, the RICO shallow cumulus case.

Indeed, the figures show that there are large difference between the models at all heights. I was expecting the causes of these differences to be explored by sensitivity testing with CLUBB (or the LES) and concrete suggestions made for how the CLUBB could be improved to better represent the LES. There is a comment about this at the end section 4, with the suggestion that model improvements are ‘out of scope’, but without further exploration of the model differences the paper is somewhat dry and technical. I suggest that a major revision is necessary, to include an adequate exploration of the causes of the model differences.

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 source of this error has been explored in a prior paper. The revised version of the manuscript provides the following explanation:

“However, in CLUBB, the range of altitudes where the microphysics budget terms have

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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. The excessive evaporation near cloud top also causes a similar problem in the microphysical terms in the other budgets presented below. See Griffin and Larson (2016) for more details."

I was expecting to see analytical results, somewhere in this paper, for the closed expressions for the microphysical covariances. The authors give expressions, e.g., Eq. (25), in terms of integrals, but do not actually evaluate the integrals in terms of the model prognostics. Given that it is the integrated expressions which are potentially useful to the reader, these should be given. This comment applies to the appendix as well.

The integrated expressions were and are contained in the Supplement, but that fact was not made explicit enough in the original text.

To clarify, the introduction now states “The needed integrals are set up in Appendix A and are solved by the expressions given in the Supplement."

In addition, the Appendix now notes that “This Appendix sets up the integrals that need to be solved in order to find the microphysical covariance terms listed in Section 2.1. The integrals set up here can be evaluated using the expressions given in the Supplement."

The highly concise notation used in Section 2.2 for the PDFs is difficult to understand. Could it be replaced with one or two, well chosen, examples? If the fully-general expressions need to be recorded here, they could be moved to an appendix.

The fully general expressions are necessary, but several illuminating examples are

listed in the Supplement. This is now pointed out just after the general form of the PDF is listed:

“Eq. 22 lists the general functional form for the subgrid PDF, but specific examples of marginals for a single mixture component are written out in the Supplement to this article. (A marginal PDF is the PDF that remains when one or more variates are integrated out.) These examples help provide intuition about the shape of the PDF. For instance, a univariate normal marginal of the PDF is written in Eq. (S7), and a univariate lognormal is written in Eq. (S8). A normal distribution is symmetric, extends from $(-\infty, +\infty)$, and has short tails. A lognormal distribution is useful for representing the distribution of a quantity such as rain mixing ratio. Such distributions are non-negative and often have a peak at low values and a long tail of larger values extending to the right. They are not well represented by normal distributions.

Also useful for gaining intuition are the bivariate marginals listed in Section S3 of the Supplement. A normal-normal bivariate form is listed in Eq. (S4), a lognormal-lognormal form is listed in Eq. (S6), and a hybrid normal-lognormal form is listed in Eq. (S5). Where a lognormal variate appears, the corresponding axis takes on only non-negative values and has a long tail. Which bivariate form is used depends on which functional forms are used to represent the variates of interest, e.g., rain mixing ratio (lognormal) or extended cloud water (normal)."

The figures comparing the LES and CLUBB often use different scales for the two models. This makes direct comparison difficult and should be corrected.

The scales for all but one of the RICO figures have been made the same. In order to make the individual budget terms more visible and distinguishable, the scales for the $\overline{\theta_l'^2}$ budget remain different, but that fact is now clearly noted in the appropriate figure caption:

“Note that the horizontal axes on the SAM LES and CLUBB panels are different."

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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