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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 #1

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

The paper integrates various microphysical terms in higher-order moment equations analytically and compares the results with those from LES.

Thank you for your review.

It is overall a very boring paper. It is more like a technical report than a formal paper. If the readers do not need to dig into the model code, One does not think a reader can go through all the formulae.

Our paper is designed to satisfy the requirements of a "Model description paper" of GMD. Model description papers are a little different than typical scientific papers. The GMD webpage on manuscript types states: "Model description papers are comprehensive descriptions of numerical models which fall within the scope of GMD. The papers should be detailed, complete, rigorous . . . ideally, the description should be sufficiently detailed to in principle allow for the re-implementation of the model by others". The formulas listed in the paper must be included for completeness, rigor, and reproducibility.

One interesting aspect of our paper is the introduction of a technique to parameterize an effect of cold pools on convection, namely the increase in temperature variance below cloud. The revised manuscript emphasizes this important application of the method with sentences such as "The fact that CLUBB is able to parameterize this effect opens the door to future parameterization of the effects of cold pools on convection."

The results are not new. Most of the them were documented in the literature.

The paper's results are new. To our knowledge, no prior publication has parameterized microphysical effects on *variances and covariances*. Those terms are present in the governing equations, but all prior 1D parameterizations have omitted them. For instance, Cheng and Xu (2009) parameterized the effects of microphysics on grid means but not (co)variances. The microphysical effects on the grid means can shift the subgrid PDF to smaller or larger values, but they cannot directly change the *shape* of the PDF. In contrast, the covariance terms change the shape of the PDF. They are important because 1) they damp variability (i.e. narrow the PDF) via the effects of precipitation rather than turbulence; and 2) they generate variability (i.e. widen the PDF) below cloud via the effects of rain evaporation.

This is now clarified in the introduction.

The differences between the analytical solution and LESs are kind of expected.

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 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."

More in-depth analysis may make the paper reach more readers and more interesting.

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.

The method is not new, for example, Cheng and Xu (2009) published a pioneer work in Journal of Atmospheric Science . . .

Prior to Cheng and Xu (2009), several articles on the effects of microphysics on *grid means* were published, e.g., Zhang et al. (2002), Larson and Griffin (2006), and Morrison and Gettelman (2008).

. . . using the similar pdfs to integrate for various micro- physical terms.

The most important difference between the present paper and Zhang et al. (2002), Larson and Griffin (2006), Morrison and Gettelman (2008), and Cheng and Xu (2009) is that those papers omit the terms that are the central focus of the present paper: the effects of microphysics on *(co)variances*.

The effects on covariances are important terms in the covariance budgets, as demonstrated in the present paper's figures. But even when the effects on covariances are important, they have been neglected in prior papers. For instance, Eqn. (16) of Cheng and Xu (2009) prognoses the variance of rain water mixing ratio using an equation that includes turbulent advection, turbulent production, and turbulent dissipation, but not any effects of autoconversion, accretion, evaporation, or any other microphysical process.

The PDF shape used by Cheng and Xu (2009) for rain mixing ratio is a double Gaussian. The present paper uses a double lognormal. Using double lognormal has a key advantage for non-negative variables such as rain: a double lognormal never takes on negative values. For rain, this is important, because rain often has a small mean and a large right-hand tail at large values. Fitting the mean and variance of this shape using a double Gaussian will leave a significant fraction of the PDF to the left of zero, which is unphysical.

The analyses and experiments are more interesting than here.

The present paper includes complete budgets, whereas Cheng and Xu (2009) does not. Complete budgets are interesting because they allow the reader to compare the magnitude of the microphysical terms versus other terms, such as turbulence terms. For example, the budgets reveal the interesting fact that in our large-eddy simulation of a shallow cumulus case, microphysical damping of scalar variances is stronger than turbulent damping! This is important because the turbulent damping term is always included in scalar variance parameterizations, but microphysical damping has always been neglected.

In addition, the revised manuscript includes the aforementioned sensitivity study in which the microphysical covariance terms are shut off.

The author do not cite this work. This is not a good scholar.

The original submission did not cite Cheng and Xu (2009), nor Zhang et al. (2002) and Larson and Griffin (2006), because those articles considered only with the effects of microphysics on grid means, not (co)variances.

The revised manuscript includes the following clarification and citations: “To clarify, we note that the microphysical terms we study here appear in the variance and covariance equations, not the grid mean equations. Microphysical effects on the grid means have been studied in several prior works (e.g., Zhang et al., 2002; Larson and Griffin, 2006; Morrison and Gettelman, 2008; Cheng and Xu, 2009; Larson and Griffin, 2013; Griffin and Larson, 2013; Boutle et al., 2014). The microphysical effects on the grid means can shift the subgrid Probability Density Function (PDF) to smaller or larger values, but, unlike the covariance terms, they cannot directly change the shape of the PDF. The microphysical covariance terms are important because 1) they damp variability (i.e. narrow the PDF) via the effects of precipitation rather than turbulence; and 2) they generate variability (i.e. widen the PDF) below cloud via the effects of rain evaporation."

Therefore, major revisions are needed.

The paper has been revised appropriately.

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