We would like to thank the reviewer for giving constructive comments/suggestions, which are very helpful in improving the manuscript. We have revised the manuscript based on the comments/suggestions. Below are our detailed responses (blue) to the reviewer's comments/suggestions.

Responses to reviewer

Review of "Influences of Entrainment-Mixing Parameterization on Numerical Simulations of Cumulus and Stratocumulus Clouds" by Xu et al. (ACP-2021-937)

While I am generally pleased with the addition of the entrainment fraction parameterization and the additional analyses, I still have some major concerns, as outlined below. Thus, I would like the authors to address the following concerns below before I can recommend the publication of this manuscript.

Reply: Thank you very much for your comments on our work. Please see the detailed responses to your specific comments below and the changes in the revised manuscript. Hope the revised manuscript can eliminate your concern.

Major Comments

Is the parameterized entrainment fraction suitable for microscale processes? Of course, the fitting seems to be successful (Fig. 8), and I like the idea of parameterizing the entrainment fraction based on the grid-scale relative humidity and cloud water mixing ratio. However, I doubt that this parameterization is suitable for a microscale process, where local shear and buoyancy drive turbulence generation and entrainment. In fact, Xu and Randall (1996) developed the applied parameterization for climate models in the 1990s, i.e., for representing entire subgrid-scale clouds at a resolution of several tens to hundreds of kilometers, while the authors apply it for subgrid-scale processes below 100 m. Finally, I wonder why the data on the x-axis of Fig. 8 is not evenly spaced? The calculated (1 – f) values should have values between 0 and 1 with a spacing of 0.01, which should be visible in the plot. Or is there some post-processing not mentioned in the manuscript?

Reply: We agree with the reviewer that local shear (dw/dz) and buoyancy (B) may drive turbulence generation and entrainment for a microscale process. Therefore, dw/dz and B are used to fit "1 - f" (Figure R1). Since some values of dw/dz and B are negative, their absolute values are taken in the fitting with the power law function. Figure R1(a) shows that the parameterization with dw/dz and B has poor performance with correlation coefficient (R) of 0.17 and root-mean-square error (RMSE) of 0.20. Figure R1 also shows the parameterization relating "1 - f" to relative humidity ($\mathrm{RH}_{\mathrm{grid}}$) and cloud water mixing ratio (q_c), which is used in our simulation; R and RMSE are 0.89 and 0.10, respectively. Therefore, this parameterization is much better than that based on dw/dz and B.

To further confirm that the parameterization using $\mathrm{RH}_{\mathrm{grid}}$ and q_c is a good choice, Figure R1(b) furthers shows the results by adding dw/dz and B to the parameterization using $\mathrm{RH}_{\mathrm{grid}}$ and q_c. It is interesting to find that the addition of dw/dz and B neither increases R nor decreases RMSE. Therefore, using $\mathrm{RH}_{\mathrm{grid}}$ and q_c to parametrize "1 – f" is good and reasonable, at least for the cases in this study. The corresponding discussions are added in Lines 418-423: "Considering that local shear (dw/dz) and buoyancy (B) may drive turbulence generation and entrainment for a microscale process, the two quantities are also used to fit "1 - f" except for $\mathrm{RH}_{\mathrm{grid}}$ and q_c. However, the addition of dw/dz and B to Equation (11) does not increase R. Therefore, using $\mathrm{RH}_{\mathrm{grid}}$ and q_c to parametrize "1 – f" is good and reasonable for a microscale process."

By the way, we recognize the possible scale mismatch concern and the Xu and Randall (1996) developed their parameterization for climate models. That's why our parameterization of "1 – f" is developed based on the large eddy simulations (LES) with a higher resolution of 10 m, instead of directly using the Xu-Randall parameterization.

In Fig. 8, the original data of "1 – f" are used without binning the data with a spacing of 0.01. The non-uniform distribution of the data points is because the occurrence frequency of individual mixing fractions is not the same. For example, no original data is in the range of 0.9 - 1 and over half of the data is smaller than 0.3.

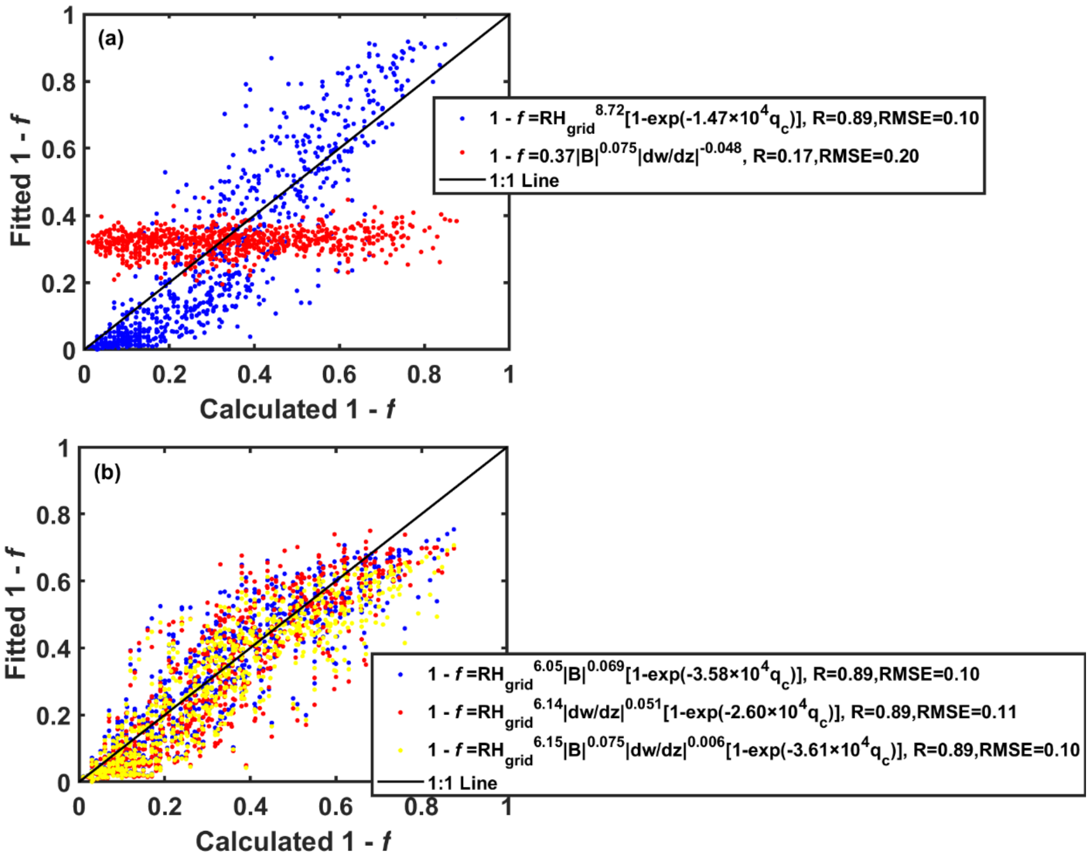

Figure R1. The fitted $1 - f$ as a function of the calculated $1 - f$. The fitted $1 – f$ is obtained by the fitting functions with different combinations of grid-mean relative humidity (RH_{grid}), cloud water mixing ratio (q_c), buoyancy (B), and vertical wind shear (dw/dz). The black lines denote the 1:1 line. Each legend provides the correlation coefficient (R), the fitting function, and the root-mean-square error (RMSE). All the p values are smaller than 0.01.

Extension of the parameterization to account for entrainment fraction. In Luo et al. (2020), the authors showed that the entrainment fraction impacts the subsequent mixing process. Why is the entrainment fraction not considered in their parameterization (6)?

Reply: We agree with the reviewer that the entrainment fraction is important for entrainment-mixing processes; however, it is very hard to obtain the accurate entrainment faction in most numerical models, including large eddy simulation (LES) models, and the parameterization proposed in Luo et al. (2020) was established for these models. To the authors' knowledge, only in the LES model used by Jarecka et al. (2009) and Jarecka et al. (2013), entrainment faction was explicitly available by adding an equation to predict entrainment fraction for each grid. Since entrainment faction is hard to be determined in other models and in observations, Lehmann et al. (2009) defined transition length for Damköhler Number equal to 1. They argued that "The transition length scale separates the inertial subrange into a range of length scales for which mixing between ambient dry and cloudy air is inhomogeneous, and a range for which the mixing is homogeneous." We understand that the transition length is not perfect, but should be a good choice when entrainment fraction is not available. Therefore, Luo et al. (2020) developed a parameterization based on transition scale defined as the ratio of the transition length to the Kolmogorov scale (Kumar et al., 2013; Lu et al., 2011). Entrainment fraction was considered implicitly in Luo et al. (2020)'s parameterization, because the Explicit Mixing Parcel Model simulations with different entrainment fraction were used to develop this parameterization.

Again, it is better to explicitly consider entrainment fraction as in Jarecka et al. (2009) and Jarecka et al. (2013) in principle. The method used in our study is an alternative way to represent entrainment-mixing process when the prognostic entrainment fraction is not available.

We have added some discussions in the revised manuscript (Lines 435-438).

References

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