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

The character of entrainment-mixing can have substantial impacts on the microphysical composition of clouds, with commensurate effects on the cloud optical properties and hence their role in the climate system. Nonetheless, most cloud models neglect the natural variability in the mixing process and assume homogeneous mixing as the default. For the application in bulk cloud models, this study develops a parameterization to consider the natural range between homogeneous and extreme inhomogeneous mixing based on simulation data derived from a high-resolution stochastic turbulence model applied in a previous study of the authors (Luo et al. 2020). After development, the parameterization is applied to a cumulus and a stratocumulus case and the results are analyzed.

The manuscript is generally well-written, interesting, and of relevance. However, there might be a fundamental flaw in the assumptions made in the parameterization development that can invalidate the entire manuscript, as I will outline further below. Therefore, I cannot recommend the publication of the manuscript at this stage.

Major Comments

Developing an entrainment-mixing parameterization that depends on the grid-averaged relative humidity. While I understand that it is necessary to simplify physical processes for parameterization purposes, the presented parameterization glances over crucial factors in the entrainment-mixing process. The entrainment-mixing process depends heavily on the relative humidity RH of the entrained air. While I agree that this variable is not directly accessible in most models, using the grid-averaged RH can be misleading if the fraction of entrained air f is unknown. To illustrate this, we make the simplifying assumption that RH mixes linearly. (More rigorous calculations can be based on, e.g., Paluch (1979).) With this simplification, we find that

$$RH_{entrained} = \frac{RH_{grid} - (1-f)RH_{cloud}}{f},$$

where the subscripts *entrained*, *cloud*, and *grid* indicate the RH in the entrained, cloudy, and grid-averaged air, respectively. While one can assume that RH_{cloud} is approximately 100 %, $RH_{entrained}$ can vary substantially for a given RH_{grid} if f is not constrained. And when $RH_{entrained}$ is not constrained, the predicted character of entrainment-mixing may be not based in physics. Thus, getting information on f is crucial for the success of the entrainment-mixing parameterization. The authors might want to refer to Jarecka et al. (2009, 2013) on possible pathways to determine f. Furthermore, I would like to emphasize that the original data on which the parameterization of this study is based uses mainly an $f = 0.2$ (Luo et al. 2020), while larger f have only been addressed in that study briefly. In fact, Luo et al. (2020) state that different f can change the character of mixing. Without addressing these issues, I cannot support the publication of the manuscript.

Minor Comments

L. 1: I would add an "an" before "Entrainment-Mixing".

Ll. 130 –134: Why do you use definition (4) here? Equation (7) might be better as it is directly coupled to the subgrid-scale scheme of the dynamical model. Or do you recommend this approach for models that do not predict ε? Please comment on this decision.

L. 140: The subsaturation is defined as 1-RH, the supersaturation as RH-1, and (5a) requires the supersaturation due to the minus.

Sec. 3: I generally agree with these results. However, the results depend significantly on how well the entrainment-mixing parameterization captures the f dependency. Thus, I do not like to add any more comments at this stage of the publication process.

Ll. 459 – 462: As most models suffer from numerical diffusion, too high supersaturations at the cloud edge are a common problem in most dynamical models, not only large-eddy simulation approaches.

Tab. 3: Add horizontal lines to associate the investigated variables more clearly with the presented values.

Fig. 1: I assume you show the logarithm of the transition scale number here?

References

Luo, S., Lu, C., Liu, Y., Bian, J., Gao, W., Li, J., ... & Guo, X. (2020). Parameterizations of entrainment-mixing mechanisms and their effects on cloud droplet spectral width based on numerical simulations. *Journal of Geophysical Research: Atmospheres*, *125*(22), e2020JD032972.

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