Replies to Referee #1 on gmd-2022-162
The reviewer's comments are shown in bold font.

The goal of this paper is to test whether the addition of a mass flux scheme, which represent non-local transport by updrafts, to the turbulence scheme called SHOC improves the representation of shallow cumulus convection by the SCREAM climate model.

For this purpose, the authors use a single-column model with the SCREAM model physics, and with or without the multiplume mass flux scheme developed by Suselj et. al (2013,2019a,b). By simulating two cloudy boundary layers and comparing them with large-eddy simulations, they show that the addition of this mass flux parameterization improves the representation and evolution of cloud features and turbulent transport.

Knowing that uncertainties in the representation of low clouds by climate models remaing important, it is still very valuable to continue working on improving these clouds. The paper presents interesting results, a relevant methodology, and is well written. Therefore, the article is very suitable for publication. I'm nevertheless concerned about the pontential implementation of the SHOC+MF in the parent 3D climate model for several reasons: the adjustement of tunable parameters, the relevance of the EDMF scheme in a model that aims to simulate at high resolution (scale awareness), and the coupling with other parameterization such as radiation, and microphysics. These points are not addressed in this study. More information about would be very valuable for the community.

We would like to thank the reviewer for the constructive comments that helped to substantially improve the manuscript. Essentially, all of the reviewer's comments were addressed by modifications and additions in the manuscript. As a result of the reviewer's comments, the manuscript was revised.

Detailed replies to the reviewer's comments are listed below.

Major comments:
1. I know that it could be complicated, but I really find it problematic that the authors avoid the question of tuning when testing their new parameterization. Here there are several parameters that need to be ajusted when combining SHOC and MF schemes, e.g. number of plumes N, epsilon_0, 'a' for the entrainment length scale, … The authors justify the tuning parameters' values by the original studies that set them. However, this study highlights a coupling between parameterizations that might suggest that these values may be outdated. Without asking the authors to test all tunable parameters, I would like to know if (1) values they use remain physically consistent in their new SHOCMF framework, and (2) if their conclusions remain similar when some important tunable paremeters are modified. I guess that the second point is feasible given the simple SCM framework the authors use.

This is indeed an important point. Even though we did not mention it explicitly in the manuscript, we did perform some tuning of SHOC+MF in order to achieve the results discussed in the paper. Our results show a good agreement of SHOC+MF relative to the reference LES for two benchmark cases; this would have not been possible without some tuning. As the reviewer likely knows well, such tuning is often essential in parameterization implementation and assessment. For the present SHOC+MF configuration, we tested *N* (number of updrafts), a_w and b_w (constants in the vertical velocity of the *n*th updraft; equation 6 of the paper), ε_0 (fraction of entrained mass-flux during each entrainment event in equation 7), and a (entrainment length scale constant in equation 8). The optimal values $\varepsilon_0 = 0.2$, $a_w = 1$ and $b_w = 1.5$ are equal to the ones used in Suselj et al. 2019, whereas a =1.25 $m^{1/2}$ instead of 2.5 $m^{1/2}$ used in Suselj et al. 2019. Also, here we use *N* = 40 updrafts. We added a new sentence in section 2.3 discussing the total number of updrafts which reads:

"Here, we use *N* = 40 updrafts. The number of updrafts was chosen based on a sensitivity analysis of SHOC+MF to its value in which SHOC+MF showed weak sensitivity to *N* > 30 updrafts (not shown). Note that a small number of updrafts can produce noisier results due to the lateral entrainment's stochasticity (Suselj et al. 2019a)."

For the results of SHOC alone, we used the same tunable constants used in the global high-resolution simulation discussed in Caldwell et al 2021 and added a sentence in L249 to clarify: "Lastly, for the simulations of SHOC alone, we used the same tunable constants from the global high-resolution simulation presented in Caldwell et al. (2021)."

2. The authors show improvements when implementing the MF scheme in SHOC. However, the heat and moisture transports remain biased low (Fig 8-9). Could the authors describe improvements to reduce this bias? Would it be possible to reduce it by a better tuning strategy or switching on radiation scheme?

Yes, it is likely that we could reduce even further the biases shown by SHOC+MF with additional tuning. However, for the reasons discussed in both major and minor comments #1, it would likely not be necessarily productive at this stage to aim to reduce the already relatively small biases of SHOC+MF shown in Figures 4, 6, 8, and 9.

Minor comments:

1. I understand that removing some parameterization schemes is useful to highlight the novelty of SHOC+MF. Yet I'm surprised that the authors removed the radiation schemes. I would assume that some large-scale cooling and drying forcing are imposed in large-eddy simulations. Removing these schemes would also compromise the ability of the model development to be used in the parent global climate model.

Because the cases that are investigated are related to shallow convection and as such are related to low values of cloud cover, the LES setup for these cases does not include interactive radiation parameterizations. The low values of cloud cover imply that cloud-radiation interaction plays a secondary role in the overall physics of these cases — as compared to the role of the surface evaporation and of the condensation in the cumulus updrafts. These LES cases do have, however, simple representations of clear-sky radiative cooling that is implicitly part of the large-scale forcing of the LES and the SCM simulations. For the SCM simulations, we also switch off the interactive radiation scheme available in SCREAM because of the reasons explained above and to allow for a clear comparison between the LES reference data and the SCM results as none of these cases accounts for interactive radiation as mentioned above.

2. Figures 1+5: I'm confused with the notation. You have two simulations SHOC (A), and SHOC+MF (B). Therefore, you plot results from A and B experiments, but also the relative contribution of SHOC and MF in turbulent fluxes (we can call it B[SHOC] and B[MF]). MF in Figure 1 seems to be B[MF], but this is confusing because MF could also be understood as the difference B-A in Figure 1. I guess that non-linear interactions could make these contributions different (i.e. B-A != B[MF]). Could you clarify this a little bit (differences between experiments vs the MF contribution that is saved from SHOC+MF) ?

The reviewer's interpretation is correct. For completeness, in figures 1 and 5, we plotted the turbulent fluxes for:

- SHOC: the turbulent flux diagnosed by the SHOC version; solid gray profiles.
- SHOC+MF: sum of SHOC and MF following $\overline{w'\phi'} = \underbrace{-K_\phi \frac{\partial\bar{\phi}}{\partial z}}_{SHOC} + \underbrace{\sum_{n=1}^{N} a_n(w_n - \overline{w})\left(\phi_n - \overline{\phi}\right)}_{MF}$ (equations 11 in the paper); solid red profiles.
- MF: the contribution of MF in the SHOC+MF equation above (the term in red): dashed red profiles.

3. Line: 311: Could you use a single time notation, either "hour XX" or "+YYh" relative to the start of the simulation (as done in Fig 4).

We edited the labels in Figures 3 and 5. It now reads "HH:MM LST (+X h)", i.e., we changed UTC to local standard time (LST) and followed your suggestion in parentheses. The captions of both figures were updated accordingly.

4. Figure 8: I don't think the dashed and the dotted-dashed lines are described.

Thank you so much for catching this. We added its description to the caption of Figure 8.