Response to the comments of reviewer 2

Our responses are marked in italic and color.

We thank reviewer 2 for his helpful comments which helped us to improve the manuscript.

This manuscript addresses an important yet poorly understood topic by examining the impact of 3D longwave radiative processes on cloud development for small cumulus clouds. The methodology is appropriate and I believe the paper will make a valuable contribution to the community, but the presentation needs significant improvement before publication. Please find below a list of specific comments. In compiling the list I tried to avoid repeating earlier comments made in the interactive discussion, but some inadvertent repetitions may occur.

General comments:

The paper should comment on whether the results are likely to be affected in a significant way by any inaccuracies in its 3D radiation scheme, the Neighboring Column Approximation.

We added an additional subsection, explaining the general performance of the NCA, as described in Klinger and Mayer, 2016 (JQSRT). We also addressed the performance of the NCA in the context of this paper.

The summary section should mention that examining additional LES scenes is a key topic for follow-up studies (alongside with incorporating solar radiation, etc.), as the representativeness of current results can be established only by examining further scenes.

We added the suggested outlook to the summary section.

Specific comments:

Page 1, Lines 9-10: The meaning of “slab-averaged applications” is not clear to me. Also, the comma after “profile” in Line 11 is not needed.

We replaced "slab average" by " a horizontal average of the 1D and 3D radiation in each layer is used"; the comma is removed.

Page 1, Lines 16-17: It would be important to clarify right at the first mention what is meant by “organization” and/or “organization effects” (e.g., fewer but larger clouds).

We modified the abstract. The term 'organization' is now explained. In addition, we also refer to the differences between the 50m and 100m resolution simulations.

Page 5, Lines 6-7: It would help to point out that averaging is over the entire scenes, including even cloud-free grid cells. (This is clarified in the last sentence of Page 13,

but readers may wonder well before that.)

We added this information on page 5: 'These averaged heating rates are then applied in the entire layer to clear sky and cloudy regions.'

Page 5, line 11: I suggest deleting the sentence "The overall cooling in a modeling domain is generally stronger in case of 3D thermal NCA radiation", as the results are discussed and explained later, while this section discusses only the experimental setup.

The sentence is deleted.

Page 6, Line 6: I wonder in what sense does cooling compensate for the temperature perturbation.

We summed the occurring cooling over time. After 40min, the amount of cooling brought into the system by thermal radiation is close to the temperature perturbation of each simulations (e.g. 0.8 or 1.6 K). We changed the text to: "Summing up the thermal cooling in our simulations over time, we found that 40 min is about the time it takes for the thermal cooling to compensate the original heat perturbation of the bubble. This time period is roughly the same in the strong and weakly forced case, because the stronger forced single clouds contain more liquid water and therefore more thermal cooling."

Figure 3 and most subsequent figures: Using longer dashes in all figures would really help, as I could distinguish dashed lines from solid ones only after strong zooming.
Figure 5 caption: It is not quite clear to me what "bottom" and "middle" mean in "bottom right axis" and "middle left axis."

We modified the figures according to the suggestions.
The caption of Figure 5 was modified to: 'Liquid water mixing ratio is shown in pale colors on the bottom, the vertical velocity is shown in middle of each figure. The corresponding axes are on the right and left respectively'.

Page 10, line 6: It might be worth pointing out that relative humidity is lower in interactive simulations even though the temperature is also lower, because the liquid water mixing ratio is higher.

We added this suggestion to the text: 'We note here that in the cloud layer, the relative humidity decreases in the local radiation simulations, because the liquid water mixing ratio is higher, although the temperature is lower.'

Figure 10-11 captions: For clarity, I suggest replacing "as an 3 hour averaged" by "and as 3 hour averages centered" (perhaps using "starting" instead of "centered").

We replaced the phrase according to the suggestion.

Page 12, Lines 27-29: It seems worth mentioning that the issues of cloud organization and the size-dependence of cloud lifetime are closely related, as smaller clouds dying and larger clouds growing will result in fewer but larger clouds and in longer correlation lengths. Also, it seems worth pointing out explicitly that it is the same entrainment-invigoration due to 3D interactive radiation that reduces cloud diameter for the cylindrical cloud and erodes small-size clouds for the LES cumulus scene (if this is correct).

We added the suggestion. We strongly suspect that interactive radiation reduces the cloud diameter, however this is not easily shown in our current simulation. This was added as a possible explanation.

Page 13, Lines 7-8: I don't quite understand the sentence "The separation into moist and dry regions is stronger in the simulation with a coarser resolution.", and so clarification would be helpful.

We meant to point out that in the 100m resolution simulations, we find areas covered by large clouds where most of the liquid water is located, while on the same time, cloud free areas (dry areas) exist.
We changed the sentence to the following which hopefully is more precise: 'We find larger areas covered by clouds and on the same time larger (drier) regions where no clouds from.'

Page 13, Line 18: The comma after "both" can be deleted.

The comma is deleted.

Page 13, Lines 27-29: It seems more important to emphasize the behavior before (rather than after) 20 hours, as that is the time period for which cloud organization results are presented (Figures 13 & 14). The time after 20 hours may be mentioned in passing, but the key point is that in the first 20 hours, clouds are larger in the interactive runs.

The conclusion is rewritten and now accounts for the suggestion.

Page 14, Lines 17-18: The sentence "
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it is not certain that we would ever reach the
stage where clouds organize in the averaged radiation simulations, but we may reach the stage in the interactive ones" is confusing, because the paper discussed cloud organization in Section 3.2.2 and did not find it negligible in the interactive simulations.

In our rewritten conclusion, this sentence is deleted.

Page 14, Lines 3-5 also talk about significant cloud organization.

See comment above.

Page 14, last sentence of summary: This is a very important sentence, and even I suggest directly pointing out its main implication, that the impact of 3D effects comes from changing the spatial distribution (and not the mean value) of cooling.

This implication is now included in the conclusion.

Figure 19 is very helpful and I would even consider bringing it earlier, accompanied by some discussion of the key processes involved. For example, it could help to point out that the difference between 3D averaged and 3D interactive simulations is determined by the balance of two competing processes. In interactive runs, the stronger entrainment caused by cloud side cooling shrinks clouds, while the lack of cooling in the middle of updraft pockets leads to stronger updrafts and helps clouds grow. The balance of these two processes varies with the perimeter to area ratio of updrafts, and so the first process can be expected to win for small clouds, and the second one for large clouds. Finally, a minor point is that it would help to include a title for each panel or to specify in the caption what the top and bottom panels are for.

We shifted Figure 19 to the main part of the paper (Section 3.2.2) accompanied by a summarizing text of the results. A title for each panel was added.

Appendix: I don't think there is a need for a separate Appendix, as the current Appendix contains only the two tables that could easily be moved into the main body. Also, it would be important to clarify what is meant by "vertical stretching".

The Appendix is removed and the contents were moved to the main text.