

## ***Interactive comment on “Effects of 3D Thermal Radiation on Cloud Development” by Carolin Klinger et al.***

### **Anonymous Referee #3**

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#### Summary:

The stated goal of this paper is to illustrate the effect of 3D thermal radiative transfer on simulated clouds. This is done by simulating a single plume cloud and a field of oceanic cumulus clouds using suite of thermal radiation configurations, ranging from no radiation to 3D thermal radiation. While this is an interesting study it is not clear what new information is brought forth. There are papers in the literature which discuss the effect of turning radiation on and off and the effect of using average instead of local radiation. New results should be the effect of interactive 3D thermal radiative transfer on the simulation but the author has missed, or at least not referenced, a key paper which has presented this sort of experiment. In addition, the results from single simulations are not particularly convincing of a clearly different response when using 3D, versus ICA, thermal radiative transfer.

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With these comments in mind, I suggest that the authors perform a major revision of the paper taking into account the comments below and previous results in the literature.

#### General comments:

Single cloud results: I would say that the results when using 1D and 3D thermal RT are almost indistinguishable and it would be challenging to read much into these results. For example, if you performed the simulations with 1D thermal RT again, or several times, but with a small random perturbation, I suspect the results would be about as different as that between the 1D and 3D. The main thing I can take from these simulations is that interactive "local" radiation has an influence versus no radiation but the complexity of the radiation parametrization doesn't seem to be too important, at least for the variables included in the analysis.

Cloud field results: I have the same comments here as for the single cloud experiment. For most of the variables the differences between results for 1D and 3D "local" thermal radiation are very similar. Is there an expectation that ensembles of simulations would show the differences to be statistically significant?

#### Specific comments:

Title: It does not accurately reflect of the contents of the paper. The 3D thermal radiation is a relatively small part of the paper and the paper focuses on a very particular types of cloud. I.e, I don't think the results could be generalized to all clouds.

References: The highly relevant paper by Mechem is missing:

Mechem, D. B.; Kogan, Y. L.; Ovtchinnikov, M.; Davis, A. B.; Evans, K. F. & Ellingson, R. G. Multidimensional Longwave Forcing of Boundary Layer Cloud Systems Journal of the Atmospheric Sciences, 2008, 65, 3963-3977.

There are some papers that have discussed interactive cloud resolving simulations considering aspects of 3D solar radiative transfer:

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Koracin, D.; Isakov, V. & Mendez-Nunez, L. A cloud-resolving model with the radiation scheme based on the Monte Carlo method Atmospheric Research, 1998, 47-48, 437-459

Frame, J. & Markowski, P. Numerical Simulations of Radiative Cooling beneath the Anvils of Supercell Thunderstorms Monthly Weather Review, 2010, 138, 3024-3047

And there are papers that discuss the effect of using domain mean radiative fluxes (here I give just two examples, I am sure there are others),

Petch, J. C. and Gray, M. E. B. (2001), Sensitivity studies using a cloud-resolving model simulation of the tropical west Pacific. Q.J.R. Meteorol. Soc., 127: 2287–2306. doi:10.1002/qj.49712757705

Cole, J. N. S.; Barker, H. W.; Randall, D. A.; Khairoutdinov, M. F. & Clothiaux, E. E. Global consequences of interactions between clouds and radiation at scales unresolved by global climate models Geophysical Research Letters, 2005, 32, L06703

Introduction, long paragraph stating at line 3, page 2: This paragraph is challenging to read and needs to be rewritten since in its current state it comes across as an "information dump". From it reader needs to pull together information needed for the remainder of the paper. Breaking the paragraph into at least two would help as would putting the information into an order that fits with rest of the paper. I.e., general effect of thermal radiation on cloud development, previous results 1D versus 3D thermal radiation and a justification for examining local versus non-local radiation (1D versus slab averages) with discussion of previous results.

Page 2 line 14: The discussion of the Guan study is a bit unclear since that study compared 3D thermal radiation against the case of no radiation, not versus 1D radiative transfer,

Page 3, paragraph at line 5: Did you add modify the equations used for the cloud microphysics to explicitly model enhanced emission by drops? My understanding of

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the papers by Harrington is that a term for the radiative heating and cooling of the drop is considered. If you did not add drop cooling to the microphysics the interpretation of this paragraph is tricky.

Page 4, line 23: Is the shape of the cloud that sensitive to the structure of the perturbation?

Page 5, line 27: Why not show the clouds simulated using the 3D thermal RT? Would it not be the most realistic? Also showing the cloud field at the 20 minute point does not make sense given the discussion in the text. The text it is pointed out that it is cloud field in the period 40-80 minutes that are to be the focus of the analysis. Why not show the cloud at that point?

Page 6, line 13: The meaning of this statement 'from about 30 min onward the cloud stays rather constant at a certain height' is not clear. What exactly stays constant (liquid water path)?

Page 6, line 15: This sentence,

"All simulations show that the liquid water path (top row of Fig. 3) is reduced by thermal radiation in this "second stage" (from about 20 min to 40 min)."

is not clear. The same reduction is seen in all simulations without any radiation. Do you mean to say that thermal radiation causes liquid water path to be less than the case with no radiation? This difference is pretty small.

Page 7, lines 1-27: This analysis seems to end abruptly or I'm missing something. There is an idea of "subsiding shells" to explain the subsidence around the edge of the cloud. As mentioned in the text, Heus and Jonker, 2005 attribute the presence of the shell to "negative buoyancy, resulting from evaporative cooling following lateral mixing of environmental air with cloudy air.". The results with thermal radiation have downdraft shells that are stronger than that in the no-radiation case.

Is it not possible to use the output from the model to further analyze and show why

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the shell is enhanced in the presence of thermal radiation? Is it the radiation directly producing more negative buoyancy, Figure 1 suggests large radiative cooling, or does it induce an environment that enhances the evaporative cooling? It must be possible to quantify statements like "This might be due to the thermal cooling at cloud tops, and in case of 3D Thermal NCA radiation at cloud sides." and "The stronger horizontal buoyancy gradient (difference between positive and negative buoyancy in Fig 6) generates enhanced turbulence and therefore stronger evaporation."

Section 3.2: What is special about the "restart time" at 3 hours? Was the model run differently up to this point?

Page 8, line 15: Are the liquid water path and other variables shown for this case averaged over the entire domain or sampled only over clouds?

Page 8, line 17: How robust are these results?

Page 8, line 19: Is it an expected result that "All quantities increase over time.". If you continued running the simulation would it go into a quasi-equilibrium state?

Page 8, line 20: Remove this sentence as it is obvious,

"The different development of the No-Radiation simulation and the radiation simulations is related to the missing cooling of the thermal radiation in the No-Radiation simulation."

Page 8, line 23: Why does the lack of thermal radiative cooling lead to a higher cloud base? It is not clear to me.

Page 8, line 25: I don't think you want to use the term "bias" here, perhaps the word "change" instead?

Page 8, line 26; Perhaps a clear term than "interactive" would be "local" since the "averaged" radiation is also interactive since it still reacts to changes in the clouds.

Page 8, line 29: What is so interesting about the liquid water path and maximum liquid water content?

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Page 9, line 4: The rate of increase in cloud fraction for the "interactive" radiation after hour 22 is nearly as large as for the averaged radiation. How does this fit into the organization hypothesis?

Page 9, line 13: Initial profiles in first column not first row.

Page 9, line 26: How significant is the approximately 5% greater liquid water content in the 3D NCA simulation at hour 10?

Page 9, line 33: Figure 11 first column, not Figure 11 (second column)?

Page 10, line 1: The 3D NCA simulations produce slightly more TKE through buoyancy in the upper cloud with stronger upward and downward vertical winds. Again, is this significant? As discussed further down in this section the more significant result is that horizontal averaging causes more significant differences.

Page 10, line 24: From the results shown I would suggest that it is not conclusive that "3D Thermal NCA" increases the results shown. The differences relative to 1D ICA are quite modest and it is not clear if they are by chance or systematic.

Page 11, line 2: spacial -> spatial

Page 12, line 14: Can you quantify that "we find larger structures earlier in the 3D Thermal NCA radiation simulation"? Staring at the plots for 1D ICA and 3D NCA in Figure 14, it is not clear how one objectively comes to this conclusion. The color contouring gives some bias toward clouds with larger liquid water path, not necessarily larger cloud structures.

Section 3.2.3: Were 3 simulations performed for each radiation configuration? If so, did the "small differences" lead to a stronger or weaker case for differences between the 1D and 3D interactive simulations? The results of the simulations, especially 3D NCA, seems rather sensitive to horizontal resolution (Figs. 17 and 18). Any speculation as to why? Should we expect different results if we reduced the horizontal resolution to 25 m?

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Page 14, line 25: It is not a strong or clear result in this paper that the 3D interactive radiation is significantly stronger than the 1D ICA radiative transfer. Therefore, this statement is not well supported.

Table 1: Horizontal resolution does not match with text, 100 m in table and 50 m in text. If it is the latter then number of gridboxes is incorrect since domain size is quoted in text to 6.4 km by 6.4 km.

Figure 5: It is very difficult to read this figure. For example, the dashed lines are almost impossible to see on the printed document. For this figure titles indicating which are symmetric cloud and which are non-symmetric clouds is warranted.

Figures 10 and 11: The solid versus dash in the legend is very difficult to make out.

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