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Comment on acp-2021-9

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Referee comment on "A large-eddy simulation study of deep-convection initiation through the collision of two sea-breeze fronts" by Shizuo Fu et al., Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2021-9-RC1, 2021

Review of “A large-eddy simulation study of deep-convection initiation through the collision of two sea-breeze fronts” by Fu et al.

In this manuscript, large-eddy simulations of conditionally unstable flow over a peninsula are conducted to examine the processes leading to the initiation of deep convection. The simulations are configured to roughly represent Leizhou Peninsula of southern China, but idealized to facilitate physical interpretation. The authors conclude that the convection develops in three “generations”, each deeper and more intense than the previous one. They explain this evolution through analysis of boundary-layer and cloud-layer thermals, which appear to widen and deepen over the course of the simulation. Experiments evaluating the sensitivity of the solution to the surface total heat flux (with a fixed Bowen ratio of 0.2) are also conducted.

I found the manuscript to be well written, the figures easy to understand, and the arguments clearly formulated. The simulations results are clearly presented, authors conduct some interesting and novel analyses to gain insight, and the conclusions are sensible. However, I think that some of the conclusions are weaker than others, due to questions on the underlying logic and the extent to which the evidence presented supports them. Therefore, in my major comments below, I recommend the authors do some modest additional analyses to strengthen what appear to be the weaker conclusions.

Major comments:

- The manuscript explains the three generations of convection based primarily based on the widening of boundary-layer thermals over the course of the event. I have two related concerns. First, it is possible that processes in the cloud layer also play a role in the deepening of convection over the day. Does the midtropospheric humidity meaningfully change over the island (specifically over the sea-breeze convergence line) during the day? How might that affect the cloud development? Also, (ii) does the entrainment and cloud buoyancy substantially change over the three generations? Past studies have established a link between boundary-layer thermal size and cloud properties, but every problem is different and it would be useful to examine whether those same hypotheses apply here.

- My second concern is a common one---the cause-and-effect relation between boundary-layer forcing and moist convection. The authors argue that the convection deepens due to a widening of boundary-layer thermals, but they haven't ruled out the possibility that the boundary-layer thermals grow in response to deeper convection. It's possibly a combination of both, and the contributions of each may not be easy to isolate. Boundary-layer thermals should increase in size over the course of the day even in the absence of moist processes, but the very large thermals highlighted in Figs. 12 and 15 may have widened after they initiated convection. As a cumulus deepens, its cloud-scale circulation expands, which can lead to a widening of the boundary-layer thermal(s) supporting the cloud. One way to address this question would be to track a few of the wider boundary-layer thermals from their origin to the point where their associated clouds reach the midtroposphere (say, 4 km). If the thermal is already large before the convection becomes deep, it would strengthen the authors' causal argument.

Minor comments

- P. 5, L.~120: Why use the Kessler scheme for a simulation of deep convection? Could this be one of the reasons why deep convection fails to initiate when you use realistic total heat fluxes? I think it would be worthwhile to perform another simulation in the intermediate-heat-flux case with an ice scheme, to determine (i) if the same ideas carry over to a more realistic cloud representation and (ii) whether the lack of ice phase is the reason convection struggles to deepen in the 500 W/m^2 case.
- Another reason your experiment might fail to produce sufficiently deep convection with a more realistic heat flux is that you are neglecting large-scale forcing for ascent, which is often significant in real-world deep convection events. With that said, I'm not sure if the case of interest exhibited any large-scale ascent.
- P. 13, L.~285: The word "grid" instead of "grid point" is used. This error reappears in numerous places, so please fix throughout.
- P. 16, L.~325: I'm confused by "N is the number of grids averaged". Beyond the

repetition of the error noted above, it is unclear whether N includes the points where w <= 0. If not, it is a conditional average.

- P. 16, L.~330: Calling the strongest cell in the first generation to be “randomly” produced is a bit misleading. In a global sense, it is not random because it forms along a highly localized mesoscale feature (a sea-breeze convergence line). But its location *along that line* is largely random.
- The explanation of the third generation of convection does not make complete sense to me. There is a discussion of how the collision of cold pools gives rise to wider boundary-layer thermals, but the authors also state on P. 21 that it is the collision between gust fronts and the sea-breeze fronts that invigorates the convection. These seem like two different arguments. Is it fair to say that the local juxtaposition of sea-breeze convergence *and* cold-pool convergence leads to the widest updrafts? That would seem to encompass both arguments.
- In the third generation, the authors point to a merging of moist updrafts to generate larger clouds. While the process sounds plausible, I wonder why this only occurs in the 3rd generation and not the other two? If the merging only occurs in the third generation and not the prior two generations, the authors should attempt to explain why.
- P. 23, L.~460: The authors claim that, “The former [z_i] measures the depth of the sea breeze”. My understanding is that z_i is the boundary-layer depth, not the sea-breeze depth. I realize that the two tend to scale together, but without that background understanding, the text seems misleading.
- I don’t see a justification for the statement on P. 24 L.~475 that, “Above ð□□§ = 4 km, the number of convective cells generally decreases with height (Figs. 17a and 17d), while the mean size of the convective cells is relatively constant (Figs. 17b and 17e).” Looking at the middle column of Fig. 17, it appears that the cloud size does increase with height.
- I also question the statement on P. 25, L.~505 that, “When the sea-breeze fronts collide near the centerline of the domain, CAPE is substantially increased due to the vapor transported by the sea breezes, and strong updrafts are produced due to the collision of sea-breeze fronts.”. I agree that the vapor transport is important, but what about the impact of the updrafts on the CAPE itself? They are likely to increase it by moisture convergence as well as generating some adiabatic cooling above the boundary-layer top.
- Appendix A, P. 26, L.~525: Here the authors mention the “maximum horizontal convergence”, but don’t specify the level at which this convergence is calculated.