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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Impact of resolution and air temperature on Large Eddy Simulation of mid-latitude summer time convection" *by* Christopher Moseley et al.

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Thank you for carefully reading our manuscript, and your suggestions for improvement. Before the open discussion phase ends, we here provide preliminary replies to your major comments. For easier readability, and for referencing, we have attached numbers to your general comments.

General comments:

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1. Title: "resolution and air temperature" -> I find this a bit confusing, as resolution is

determined by the model configuration, but air temperature is not a model parameter (it impacts the simulated convection, rather than the simulation itself). Maybe mention "sensitivity to 2m temperature" specifically?

Reply: We suggest to change the title to: "Impact of resolution on Large Eddy Simulation of mid-latitude summer time convection", thus leaving out the temperature sensitivity.

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2. It would be good to add some further information about earlier studies that have looked at sensitivity of convection to resolution. One term that has come up in recent years is so-called bulk-convergence (i.e. the convergence of larger-scale mean properties) as opposed to structural convergence (e.g. Langhans et al 2012, https://journals.ametsoc.org/doi/full/10.1175/JAS-D-11-0252.1, Panosetti et al 2019, https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/qj.3502).

Reply: Thank you for drawing our attention to these studies. Panosetti et al. (2019) write that they find neither bulk-convergence nor structural convergence over Germany at the 1 km grid spacing scale. Their highest resolution simulation has 550 m grid spacing which is close to our outer ICON-LEM nest with 625 m grid spacing. Although we analyze all simulations on the same grid, our study mainly addresses structural convergence, as it is mainly concerned with the shape, time evolution, and organization of individual convection cells, rather than mean quantities averaged over areas that are larger than individual clouds. Our conclusion is that there is no structural convergence at grid spacings that are coarser than the 100 m scale, which is consistent with Panosetti et al.. In the revised manuscript, we will mention the concept of bulk- and structural convergence in the Introduction, and refer to it in the discussion of our results.

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3. p4, l26: The authors mention they have resampled their results on a larger grid. Although such a resampling is a good idea, it is important to be aware that the method used may influence the results. For example, it is likely that the cloud fraction increases due to the resampling, because some grid cells will only partially meet the threshold (this is certainly the case if non-zero liquid water would be used as the mask). It is not fully clear to me how this can be prevented, but it may be worth describing the possible effects. One alternative strategy for regridding would be to randomly sample one of the columns: this would keep the cloud fraction the same (statistically). This may also be relevant to the track statistics (section 3.3.)

Reply: There are several reasons why we applied a regridding. The primary reason is that the original ICON-LEM output is given on an unstructured triangular grid. The codes for the calculation of the indices, and the rain cell tracking, need a regular lat-lon grid as input, and an extension of our codes to handle the unstructured raw data would be a difficult task. The second reason is that we prefer to compare the data of the three different model resolutions, and the radar data, on the same grid, to reach a fair comparison. We chose a 1x1 km lat-lon grid, since this is roughly the resolution of the radar data. Further, it is only slightly coarser than the resolution of the coarse ICON-LEM resolution with 600 m grid spacing of the triangle edges. However, as the effective resolution of the ICON-LEM data is larger than the grid spacing, we can assume that there is no loss in resolution at least for the 600 m simulation. A similar regridding has also been used for other studies which also analysed ICON-LEM output, like Heinze et al. (2017), and Pscheidt et al. (2019).

As you point out, there could be some problems that the cloud edges are not clearly defined, since the resampling may lead to lower values such that the threshold may not be reached at some grid boxes. However, since we track the surface precipitation field, with a relatively low threshold of 1 mm/h rain intensity, we assume that this effect is rather small at a resolution of 1 km. In Moseley et al. (2013) (https://doi.org/10.1002/2013JD020868) it was shown that at least for radar data over

Germany, the rain cell tracking result is not largely different if the resolution is 1 km or 2 km. We will mention this is the revised manuscript. The conservative remapping method also takes care that the total amount of rainfall is not changed, which is not the case with a random sampling of columns.

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4. Section 2.4: It would be good to add some more information on the interpretation of and differences between some of the indices of convection, such as SCAI and COP. It is not clear to me what the advantages of using one metric over the other would be from the current description.

Reply: A more detailed discussion of the organization indices and the differences between them is given in Pscheidt et al. (2019). This study uses the same simulation domain as our paper, and partly the same data. Therefore we can refer to it for more information on the indices, their general behavior over the study domain, and how they should be interpreted. The purpose of our present study is mainly to show which of these indices are affected mostly by model resolution, and investigate their sensitive to daily mean temperature. Another main purpose of our study is to show that the rain cell tracking method can add additional information on the temporal evolution of convective organization that the indices can not provide, since they only “see” the spatial distribution of convection at instantaneous time records. For these reasons we decided to calculate and present all four indices SCAI, COP, I.org, and I.shape in the paper.

In their conclusions Pscheidt et al. write that since COP and SCAI are mainly influenced by the areas and the number of objects, respectively, they recommend to use I.org, I.shape, object area, and object number for characterizing the state of the spatial organization of the convection field. They also claim that I.org is in some respects superior to COP and SCAI, since it is able to distinguish between three possible categories: Organized, regular, and random. We will include this in the Discussions section of our paper.

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5. One of the metrics which is currently missing, and may be helpful in terms of the interpretation of the other indices, is a probability distribution function of object sizes in each simulation and the radar. This could potentially be plotted both for the original data and the resampled data.

Reply: We will plot some PDFs of cloud sizes for the three different model resolutions, and for the radar data, respectively. We also plan to include an additional plot comparing the size distributions in the revised manuscript. As we did not save the original data but only the regridded data-sets, we can perform this analysis only on the regridded data.

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6. One potential issue with some of the metrics, e.g. Iorg, may be that it can give disproportionally high importance to smaller objects. One option here would be to consider a measure of organisation that considers objects of the same size (see e.g. Neggers et al 2019, https://journals.ametsoc.org/doi/full/10.1175/JAS-D-18-0194.1). It would be good to mention this in the text.

Reply: Thank you for recommending this interesting study. Neggers at al. write that spatial organization affects both ends of the cloud size PDF, but in different ways: While the number of large clouds increases, there is an enhanced variability in the number of small clouds. This suggests that it is probably possible to extract more information on the spatial organization of convection, if new indices can be defined that take into account smaller and larger clouds separately. However, in our study, we are mainly concerned with deep precipitation convection where cloud sizes below 250 m are neglected, while Neggers at al. look also at smaller shallow cumulus clouds.

We will discuss this possible shortcoming of the indices in the Discussion section in the revised manuscript with reference to the study by Neggers at al.. However, the

improvement of existing indices for the spatial distribution of convection is not the main purpose of our study (see reply to your comment 4), and a subsampling analysis similar to Neggers et al. would be beyond the scope of the paper.

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7. In section 3.4, there seems to be a significant difference between all simulations and the radar in terms of the organization indices. It would be good to investigate the cause of this in more detail, for example by looking at object size distributions, or the original fields from which the indices were derived.

Reply: As stated in our reply to your comment 5, we are going to plot some size distributions for the 3 resolutions and the radar data, and discuss the differences, and their possible impact on the indices. Are you referring to Fig. 3 (as there is no section 3.4 in the manuscript)?

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8. One striking feature of figure 3 is that the development of SCAI looks different between different days. The other metrics seem to have a very similar development on different days, and for COP and I-org, the differences between radar and simulations are of the same order as the differences between the development of the indices on different days. This may point to the SCAI being more useful than some of the other indices.

Reply: As we mentioned in our reply to your comment 4 with reference to Pscheidt et al. (2019), SCAI is mainly influenced by the number of objects. The strong differences in SCAI between different days thus hint to different numbers of convection cells on the different days. On the other hand, the observation that COP and I.org are more robust among the days could mean that the size distributions do not vary that much among days.

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9. One aspect of SCAI that I am wondering about is the fact that it seems to be consistently low at night. This may partially be due to organized propagating systems, but I am also wondering how the SCAI behaves when convection is (almost) absent? Is there a strong correlation between SCAI and cloud cover?

Reply: As SCAI is strongly affected by the number of objects, and the number of objects is larger when there is strong convection, it seems plausible that SCAI is larger at noon time when convection sets it. At night, precipitation is mainly large-scale, with larger, but fewer objects and weaker intensities. SCAI already begins to decline in the afternoon hours, which reflects the observation that convection begins to organize and forms larger objects due to merging, thus reducing the number of objects.

We did not store the cloud cover field fields, but we can check if there is any correlation of SCAI with the cloud liquid water field. However, we point out that our study focusses on daytime convection, since it is known that the nocturnal boundary layer is not sufficiently resolved at LES resolutions of 100 m and coarser, which may introduce unknown biases in cloud cover at night. See e.g. van Stratum and Stevens (2015) https://doi.org/10.1002/2014MS000370. We will mention this paper in the revised manuscript.

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10. What explains differences in night-time behaviour between cool and warm days?

Reply: As stated in our previous reply, we cannot make any statements on night time precipitation from our LES simulation, since the nocturnal boundary layer is unresolved. Therefore we condition or analysis on daytime temperatures between 8 and 20 UTC, only. To make this clearer, we will limit our plots to the time range between 6 and 21 UTC in the revised manuscript.

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11. The results should likely be interpreted in the context of a given configuration.

It would be worth stressing that changes to e.g. the microphysics scheme, as well as further changes to the turbulence scheme mentioned already, will impact on the results. - In figure 8, again there seem to be differences between radar and ICON in terms of Ishape and COP, which are bigger than the differences between warm and cool days. Do you understand what causes these differences?

Reply: As we neither have sensitivity studies with different turbulence schemes, nor with changed microphysical parametrizations, we cannot make any statements on the impact of different schemes on our results. We agree that there might be significant impacts on organized convection. We will make this more clear in the discussion section, and encourage further studies in this direction.

The lower COP and higher I.shape in the model data as compared to radar hint at an under representation of convective organization and more compact objects in the 625 m LES, respectively. However, radar and model agree that organization is stronger on warmer days. The reason for the suppressed organization could be related to the too explosive convective initiation at coarser resolutions as discussed on p. 19 l. 9-18. As soon as a convection cell sets in, it is already fully developed and does not have enough time to interact with neighbouring cells within its life time. However, this is a hypothesis that should be tested in a future study. Such a study should investigate the processes that happen within merging cells more deeply.

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12. p19, l11: "larger clusters". I am not sure if this can be said on the basis of the statistics provided. Can you clarify?

Reply: This statement mainly refers to the interpretation of the tracking analysis, notably the numbers shown in Table 1. They show that the number of “solitary” tracks (i.e the convection cells that do not interact with others by means of merging and splitting), and their contribution to total rainfall, is lower for higher resolution. Vice versa, the total contribution of the tracks that undergo merging and splitting is clearly higher for the better resolved simulations. From this observation we draw the conclusion that there is more clustering happening at the higher model resolutions. The radar results looks somehow in between, with more clustering than in the 625 m model result, but less than in the finest resolution. We will clarify this in the revised manuscript.

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