Response to RC 2

Effects of Model Grid Spacing for Warm Conveyor Belt (WCB) Moisture Transport into the Upper Troposphere and Lower Stratosphere (UTLS)—Part I: Lagrangian Perspective

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Specific comments

- P5, L149-151: The choice of two-way coupling introduces a significant challenge for attribution. Because the nested grid feeds back into the global domain, the "nested" setup will naturally diverge from the "global" control, eventually resulting in different synoptic states, in particular towards the end of the simulation period. Consequently, it is intricate to tell whether the reported differences are a direct result of increased resolution or simply a byproduct of this dynamical divergence. I would like the authors to clarify their rationale for this setup, as this could be avoided by employing a one-way coupling where the synoptical state in the global domain is identical between "nested" and "global" setup.
  Thanks for this insightful comment. We have chosen the two-way nested set-up to be able to capture the full WCB outflow in our simulation. The highest resolution nest contains mainly the ascent region of the WCB, which is where embedded convection will occur and where high-resolution will most likely make the largest difference. It is computationally too costly to cover the entire domain with this highest-resolution and likely physically not necessary. We therefore choose to have the WCB outflow in coarser resolution in a two-way nested configuration so we can investigate the impact of the convection-permitting physics on the WCB outflow. This would not be possible with a one-way nested configuration. Indeed the later may introduce numerical issues at the lateral boundaries, if the system is not fully encapsulated in the highest-resolution domain.
  However, we agree that is mandatory to check how far the global and nested simulations have divergent in terms of the synoptic-scale meteorological features by the end of the simulation. Fig. 1 shows the mean sea-level pressure and the column integrated condensate content at the end of the two simulations (both in the global domain, i.e. the one with the largest grid spacing): The simulations are similar in the large-scale configura-

tions with only minor shifts in the synoptic-scale pressure pattern across the North Atlantic and Europe. There are more pronounced differences in the cloud field, particular in the region of the WCB outflow and the cold-frontal cloud structure. However, we think this is mainly due to the difference in the representation of convection due to (i) the similarity of the synoptic-scale flow pattern and (ii) the fact that WCB outflow parcels will have started to rise about half-way throughout the simulation, where the simulations have diverged even less than seen in Fig. 1.
To more clearly motivate our choice of model configuration and the implications for attribution we have added a few sentences in the model description (see lines 156-159 and 170-175 in the revised manuscript).

- A potential concern regarding the comparison between the "nested" and "global" simulations is that the trajectories are evaluated at different horizontal resolutions. Without a scale-aware framework, it is difficult to determine if the reported differences are due to resolving finer-scale or merely methodological. To isolate the added value of the finer resolution, I recommend that the authors coarse-grain the nested trajectories by averaging them within the spatial footprint of the global grid boxes. If the discrepancies persist after this upscaling, they can be more confidently attributed to the non-linear effects of resolving finer-scale processes.
  It is true that the instantaneous values as seen along the trajectories are derived from Eulerian fields of different resolution. However, we think that the distribution of values still reflects systematic differences between the model simulation, because if the high-resolution simulation would only add "noise" one should see mainly a broadening of the distributions instead of the systematic shifts identified in our analysis. However, we agree with the reviewer that the resolution difference of the fields is one of the aspects of the Lagrangian analysis that limits the generality of the results obtained in the present analysis. To address these issues, the paper has a companion Part II paper, which investigates the WCB outflow properties in an Eulerian coordinate system (there we take care of coarse-graining the

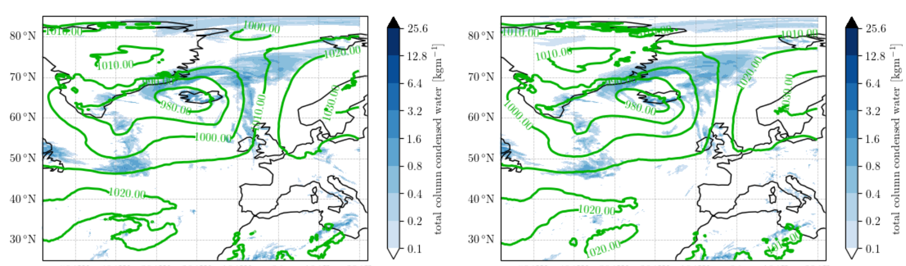

Figure 1: Mean sea-level pressure and column integrated condensate content at the end of the (a) global and (b) nested simulation, i.e. 28. 09. 2017 00 UTC.

fields in an appropriate manner). The findings of the Eulerian analysis are similar to the ones reported in Part I, which corroborates our hypothesis that the systematic shifts in the distribution of WCB properties are not due to simple higher resolution of the fields in one of the simulations. The proposed method of coarse-graining trajectories after the simulation to the global resolution may introduce biases if the trajectories are not domain-filling (which they are not) as certain regions with e.g. convergent flow features may be overrepresented. Also trajectory output is only available every 30 min, which further limits the domain-filling nature of the trajectory data-set. Probably the correct way to avoid the impact of resolved finer-scale structures would be to coarse-grain the fields before computing the value of the trace variables, which however would need to be done during the simulation. This is technically challenging (not least because of the domain decomposition used in ICON for parallel computing) and not possible within the scope of the revisions of this manuscript.
For the reasons detailed above, we refrain from coarse-graining the trajectory data-set in the manner suggested by the reviewer. However, we added a sentence alluding to the difference in resolution of finer-scale structures in one of the simulations in the discussions part of the paper (see lines 635ff).

Minor Remarks

- P11, L281: "... at one ..."; I assume you mean "... are on ... "
  Correct, thank you for pointing this out.

- P12, L290-292: Here, the authors state that the underlying distributions are different between the two setups, but you nevertheless report mean values. As the mean is a parametric quantity that is dependent on the underlying distribution, using means to compare the quantities is only valid if the underlying distributions are equal. I would therefore refer to reporting mean values, but rather median values, as they are independent of the underlying distribution. Please check for further occurrences in the manuscript.
  Yes, the median should be preferred if the distribution shape strongly differs. However, while the distributions due change somewhat between the two simulations, the are still similar enough to not introduce systematic biases when comparing the means instead of the medians. For the example given here, the mean q_v are 0.216 g/kg and 0.212 g/kg for the global and the nested simulation, respectively. The median q_v values are 0.171 g/kg and 0.155 g/kg. While the median values is smaller than the mean, the relation between the simulations is not changing. This further corroborated by the closeness of the mean and median values in the pressure-binned data (e.g. Fig. 5 b) that is already included for all variables of interest in the paper. However, we added the median values to the text (on top of the

mean values).

- P15, L362-363: "... increasing ..."; change to "...increases..."
  Done.

- P19, L472-473: I would also see a second effect that might cause the stronger graupel production. Due to the higher vertical velocities, saturation with respect to water can be more easily sustained, which might to some extent compensate for the depleting effect of the Wegener-Bergeron-Findeisen process for liquid hydrometeors, thereby causing higher graupel production.
  Thanks for the insightful comment. Higher vertical velocities may indeed influence the efficiency of depletion of supercooled liquid water due to higher condensation rates. Indeed higher vertical velocities could also result in a larger number of cloud droplets being transported to the mixed-phase region due to smaller N_c and a different ratio of the lifting timescale to the timescale of rain production by collision-coalescence. Higher condensation rates are indeed identified in Fig. 8 for the ascent region. Also, higher q_c and N_c values are found in the nested simulation in the lower part of the mixed-phase region (700-800 hPa), while they are almost identical at higher altitudes (Fig. A14 a and b). However, q_r and N_r are also slightly larger in the lower part of the mixed-phase region making the conclusions less clear.
  We have added the alternative hypothesis for the enhanced riming rates as suggested in lines 486ff of the manuscript.

- P26, Fig. A1: For better orientation, I would ask the authors to unify the geographical extent and add coastlines.
  We have updated the figure as requested.

- P22, L516: "... below pressures of above 500 hPa ..."; It is not fully clear to me what the authors mean here.
  Thank you for pointing this out, we have removed the word "above". The trajectories remain below 500 hPa.