Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2020-1160-RC2, 2020

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Shallow Cumulus Cloud Feedback in Large Eddy Simulations – Bridging the Gap to Storm Resolving Models" *by* Jule Radtke et al.

Anonymous Referee #2

Received and published: 16 December 2020

Review of "Shallow Cumulus Cloud Feedback in Large Eddy Simulations — Bridging the Gap to Storm Resolving Models" by Radtke, Mauritsen and Hohenegger, ACP-2020-1160.

Summary:

An idealized shallow cumulus case based on the RICO field campaign is simulated at a number of horizontal resolutions with and without idealized warming perturbations. These simulation are performed in a single model, the ICON-LEM. The authors find that cloud fraction in the present day climate are proportional to grid spacing. Similarly, the decrease in cloud fraction with idealized warming perturbations is also proportional

to grid spacing. The highest resolution simulations suggest (very) small positive cloud feedbacks in response to warming. This result is robust to the inclusion of precipitation and the type of warming perturbation, i.e., uniform in the vertical or moist adiabatic.

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Assessment:

The paper is focused and clearly written and illustrated with figures. I have only minor suggestions, mostly related to additional references and clarifications.

Recommendation: Minor revisions.

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Minor comments/additional references:

1. Blossey et al (2009, JAMES, https://doi.org/10.3894/JAMES.2009.1.8) also includes a study of the effect of changes in horizontal and vertical grid spacing on shallow cumulus clouds in two dimensional simulation across a similar range of resolutions as in the present paper. See in particular section 4 and figure 8 of that paper. Those simulations were based on composite low cloud regimes from a superparameterized global simulation and sought to understand the robustness of a negative low cloud feedback in that model. While the sign of the cloud response to warming was different in that setting, the same message emerged as in the present paper: higher resolution led to smaller cloud fractions and a weaker cloud response to warming in one of the cases considered in that paper. The setup in those simulations was more complicated than here, including an adaptive large-scale vertical velocity based on the weak temperature gradient approximation.

2. I didn't understand from the paper whether the RRTM radiation computation was offline, meaning that the fluxes were computed but the heating rates not applied to the ICON LEM fields, or online, meaning that they were. The description on p3/l68-69 suggests that they were offline, because the Van Zanten et al large-scale forcings (which in

part represent radiative heating) are applied in the boundary layer. I would ask the authors to make this distinction clear in the text and also to refer the reader to the appendix for more details. Whether the radiation computation is online or offline, the results of the paper are worth publishing. If longwave radiative heating is not included in the simulations, I would ask the authors to mention Narenpitak and Bretherton (2019, JAMES, https://doi.org/10.1029/2018MS001572) who found a negative shallow cumulus feedback that was driven in part by stronger LW cooling of the trade cumulus BL in a warmer climate. See also Wyant et al (2009, JAMES, https://doi.org/10.3894/JAMES.2009.1.7) who earlier hypothesized this mechanism. Narenpitak and Bretherton also considered two resolutions, 100m and 4km, in their simulations.

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Specific comments (3/58 means p. 3, line 58):

3/58: It would be useful to the reader to know what cloud droplet number and/or aerosol concentration was specified for the precipitating simulations. This could be moved to the appendix if necessary.

5/106: Would it be worth citing Cheng et al (2010, JAMES, https://doi.org/10.3894/JAMES.2010.2.3) who looked at the effect of differing horizontal resolution in the present day setting? If there are multiple studies along these lines, it could be phrased as "(e.g., Cheng et al, 2010)".

7/123-130: Is there a good reference that talks about the changes in mixing in shallow clouds as resolution decreases?

8/139: It might be worth citing Albrecht (1993, JGR, https://doi.org/10.1029/93JD00027) just after "... because it removes moisture available for evaporation near the inversion."

10/180-188: I would suggest using the phrases "cloud amount feedback" and "cloud optical depth feedback" here, as is done later in the paper.

11/194: The uniform warming perturbation implies a negative change in EIS from present day to warmed climate. Following the climatological fit of Wood and Bretherton (2006), this would imply a decrease in cloud fraction is expected (if one assumes a similar relationship in a future climate). However, the response of this particular case does not seem to follow that prediction. This is just a comment and doesn’t need to be acknowledged in the paper.

14/259-262: Presumably the shallow cumulus feedback will be an aggregate feedback over a number of cloud regimes, weighted by the frequency of occurrence of those cloud regimes (which itself could change with climate). The case presented in this paper predicts the cloud response in one of those cloud regimes. If the high-resolution cloud fraction and/or SWCRE differ from the observed mean in shallow cumulus regions, would the near-zero cloud feedback predicted by the present study be expected to carry over to those other regimes?

15/282: It would be good to be explicit that \partial_t \Theta in the table is equivalent to Q_R here in the text. The caption to the table also uses a small \theta in \partial_t \theta, while the table header uses \Theta. It would be good to be consistent.

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Typographical suggestions:

7/136-137: suggested rephrasing: "... are very similar, the inversion height in the precipitating case with 500m and 5km resolution is around 150m and 350m lower, respectively, than in the non-precipitating case ...". I felt like this wording would be easier for the reader to follow.

12/212: Suggested re-wording: "... responds to warming in both precipitating and non-precipitating simulations." I think that the emphasis on "both" is helpful for the reader.

14/253-254: Suggested re-wording: "All in all, the decrease of cloud cover and increase in cloud water with warming compensate and result in convergence to a near-zero trade wind cloud feedback at high resolution in these simulations."

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