Author Response to Reviews of

Vertical grid refinement for stratocumulus clouds in the radiation scheme of the global climate model ECHAM6.3-HAM2.3-P3

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RC: ***Reviewer Comment***, AR: *Author Response*, ☐ Manuscript text

1. Report #1

RC: ***I thank the authors for their considered response to comments on the previous version of the manuscript. In my estimation, this manuscript has addressed the comments adequately and should be accepted for publication. As was mentioned in the previous reviews, the results are essentially negative, making it a little bit of a challenge to review (probably even more so to write). The authors have provided context for the results that include physical understanding in terms of the structure around the inversion and the limitations of Sundqvist-type schemes as well as relating to other models and other methods. There are several potential avenues for future work identified, including extending the grid refinement to the microphysics or adopting a different approach as in Weverberg. Although the approach used here is not novel, it documents a new implementation in this model, and the results differ from those shown with other models. This may not be the final word in terms of understanding why the grid refinement approach may not always work well, but I think it is a positive step toward improved understanding of inversion reconstruction approaches and their limitations.***

AR: *Thank you very much for your feedback and review.*

2. Report #2

RC: ***Thanks to the authors for their efforts in revising the paper. The updated manuscript is significantly improved, and I can now see a path to publication. However, I have a few clarifications & queries arising from the responses:***

AR: *Thank you very much for your feedback and review. Please find our answers to your comments and questions below.*

RC: ***I apologise for my slightly misleading comments about Boutle & Morcrette 2010. The discussion in there that I was thinking of was: "Cv and the condensate amount (qc) are obtained from averages of Cv and qc on the sublevels, and are used when calculating the microphysical transfers that lead to the formation of precipitation (Wilson and Ballard, 1999)." i.e. when the UM is run with a diagnostic cloud scheme (similar to ECHAM-HAM), the sub-level interpolation method is used to create new (increased) values of condensed water and volume cloud fraction, which are communicated to all parts of the model, not just the radiation. It was this experiment that I was suggesting with SC-SUND, i.e. in that case, a very similar***

thing is happening - you are diagnosing new (increased) condensed water values, which could be passed to all parts of the model, not just the microphysics. You would still be using the volume assumption for cloud fraction. I agree that in your application of SC-VOL and SC-MAX, where you only calculate the area cloud fraction, and do not alter the condensed water, it is only appropriate to pass this to the radiation (as with the prognostic implementation discussed in Boutle & Morcrette 2010 which you mention).

However, your answer to the next point makes me think that this probably wouldn't actually be that helpful, because it appears that the amount of additional cloud being created by SC-SUND is negligible. Do you understand why such a negligible amount of extra condensate is created with SC-SUND? The increase in fraction (up to 30%) seems quite significant, and presumably given the constrained link between fraction and condensate in the Sundqvist scheme, the increase in condensate is commensurate to what would otherwise be obtained in clouds of this fraction?

AR: *In SC-SUND the water condensate is calculated as in SC-VOLUME (cf. Sec. 2.2.3, Eq. 11), i.e. potentially increased in the ambiguous layer but overall conserved. The Sundqvist cloud cover scheme is based only on relative humidity, i.e. the amount of water condensate has no effect. Therefore in SC-SUND the cloud cover is increased because of the higher RH but the amount of water condensate is not affected. In our schemes the water condensate amount is based on the pre-existing values and so is not automatically increased proportionally with the cloud cover increase. Normally the cloud microphysics scheme is run after the Sundqvist cloud cover scheme to calculate appropriate water condensate values. In our case, as previously mentioned, adapting the microphysics scheme to allow it to use the new grid and newly calculated values of cloud cover, T and q_v in the cloudy layer would be a major undertaking and was out of the scope of our study. This is what we would suggest as potential future work to improve the efficacy of SC-SUND.*

RC: ***Which leads me to a further question/clarification. My understanding is that SC-SUND is only used to create new clouds where previously there were none? What if it were also used to increase the water content of pre-existing clouds? The inversion sharpening code could be used in exactly the same way to re-diagnose the water content of previously existing clouds. If, what you have discovered so far, is that clouds with fraction of 0-30% are radiatively unimportant due to small water contents, increases to the water content of previously existing clouds should stand a better chance of being radiatively important. Is it the case that the increase in water content with the Sundqvist scheme is quite sensitive to the cloud fraction, i.e. increasing fraction from 0-20% gives a smaller increase in water content than increasing from 40-60% would (for example)?***

AR: *In SC-SUND the cloud cover is also re-diagnosed with Sundqvist for layers which already contained a cloud. The water condensate content is not affected for neither pre-existing clouds nor new clouds (see our answer to your previous comment). We have found that running the Sundqvist scheme on the new grid results in the formation of a new cloud (i.e. new cloud cover > 0 where condensate is present) up to 30% of the time in Sc regions (Fig. 9b). However we have also seen that these new clouds are not radiatively important because the condensate amount is too low (Fig. 10), as indeed it is not appropriately re-calculated by the microphysics scheme to be in line with the new cloud cover. This is a limitation of SC-SUND that would be corrected by extending the new grid representation to the microphysics routine.*

RC: ***I would still push the authors to investigate some combination of the above experiments, as I feel it could be useful in understanding what is going on. Certainly some further discussion on the behaviour of the Sundqvist scheme and why it does not produce much condensed water at low cloud fractions would be useful.***

AR: *The purpose of the Sundqvist scheme is only to diagnose cloud cover, based on RH; it is not meant to produce or alter condensed water (see our answer to your previous comments). We have added some discussion* *clarifying this.*

RC: ***I also think that you could strengthen some of the discussion about the frequency of occurrence of stratocumulus clouds in the model (and perhaps include this in the abstract). I think this strengthens your work. The methods you propose are only really useful for targeting errors in "amount when present" (with the exception of SC-SUND). But it appears the main bias in the model is in "frequency of occurrence", and therefore it is possibly unsurprising that the proposed changes have limited benefit. It could be argued they would be much more successful in models with good frequency of occurrence and poor amount when present.***

AR: *Thank you for the suggestion. The main practical limitation of the method comes from the inversion layer/cloud layer mismatch rather than the stratocumulus occurrence frequency in general, but the framing of the method as targeting "amount when present" errors is useful. We have added the discussion of these points and also highlighted them in the abstract.*