Reviewer comments appear in *italics*.

This paper addresses the question as how the radiative impact of clouds in an atmospheric GCM depends on assumptions regarding cloud overlap and subgrid-scale variability in condensate amount. Qualitatively, the basic results are obvious to those who know the subject well. Within the applicability limits of the Independent Column Approximation, the radiative effects of a single cloud layer are maximized by distributing the cloud condensate homogeneously- basically because cloud SW albedo and LW emissivity both depend weaker than linearly on the condensate amount (or cloud optical depth). This also applies to a multi-layer cloud field in a GCM grid column. Thus, if the cloud field as a whole is made more heterogeneous, either by making the individual cloud layers more inhomogeneous, or by adjusting the overlap closer to maximum overlap, so that the cloud condensate in a GCM grid column is packed into a smaller part of the column, domain mean cloud radiative effects (CRE) become weaker: that is, a positive change in SW CRE and a negative change in the LW CRE. The question then is, how sensitive the SW and LW CRE are to these assumptions. Although this question has been addressed before in some studies, especially for cloud fraction overlap, the present study has the asset that the authors use in their tests two different cloud schemes in the GEOS-5 AGCM. This allows at least a case study of to which extent the sensitivities depend on the properties of the GCM cloud field. Another useful aspect is the consideration of observation-based vs. globally constant decorrelation lengths (although this was also discussed in Barker (2008b; paper cited in the manuscript).

SPECIFIC COMMENTS:
One of the main results of the current work is that the impact of cloud fraction overlap is rather strongly cloud scheme -dependent, while the impact of cloud heterogeneity is more robust - provided that a similar specification of cloud heterogeneity is used for both cloud schemes, which is the case here. The strong cloud scheme dependence of the impact of cloud overlap is explained in the paper in terms of greatly different cloud fraction frequency distribution for the two cloud schemes. I wonder if there is any simple physical explanation for the similar cloud heterogeneity effects for the two cloud schemes?

The similarity in cloud heterogeneity effects is a an interesting observation. It may indeed be fortuitous to some degree. We discuss it in our response to the related question below.

Judging by Figs. 2, 3 and 10, I would guess there is some compensation between different factors. McRAS-AC has substantially higher global-mean cloud fraction than CTL, which would suggest that the heterogeneity effects also be larger for McRAS-AC. However, in fact, in Figs. 2 and 3 the effect of cloud heterogeneity on SW CRE is slightly smaller for McRAS-AC (the difference between EXP4 and EXP3 being 6.3 Wm-2 for CTL and 5.2 W m-2 for McRAS-AC). Perhaps this is due to clouds being optically thinner? Note that there is not much difference in the global mean CREs in spite of the larger total cloud fraction for McRAS-AC.

Yes, this is exactly what is happening. The McRAS-AC scheme is tuned so that the radiation scheme ultimately sees less water path. This, in conjunction with generally larger effective radii than the (essentially prescribed) effective radii of CTL results in optically thinner clouds. On the flipside, the greater effect on LW CRE in McRAS-AC compared to CTL of introducing inhomogeneous clouds (from Exp. 1 to Exp. 2) is probably also due to the optically thinner clouds in McRAS-AC, given the different sensitivity to optical depth of LW flux. Unfortunately, cloud optical depths are not part of standard model diagnostics (this is about to change with the implementation of COSP which will allow us to compare model optical depths to those of MODIS), so we cannot show optical depths distributions explicitly at this stage. Another secondary contribution to the smaller McRAS inhomogeneity effects in the SW may be our parameterization of cloud inhomogeneity itself where clouds are less inhomogeneous between 0.9 and 1 cloud fraction, a range which is more frequently encountered in the McRAS simulations.

A previous study that addresses pretty much the same questions as this one (namely, the radiative flux sensitivities to cloud fraction and cloud condensation overlap and the degree of subgrid-scale variability) is Barker and Räisänen (2005). Among other things, this study shows, like the present manuscript, that the decorrelation length for cloud fraction overlap is more important than that for condensate. This study should be cited in the present work.

Duly noted. This was indeed an omission that we have now rectified in our discussion in section 5.1.

The first paragraph of the Introduction is perhaps too much "written for the specialist". It is completely void of references. For example, "optical depths that have been greatly adjusted" could/should augmented by references (e.g., Tiedtke's (1996) optical depth tuning factor 0.7).

Another valid point. We have added references about this topic.

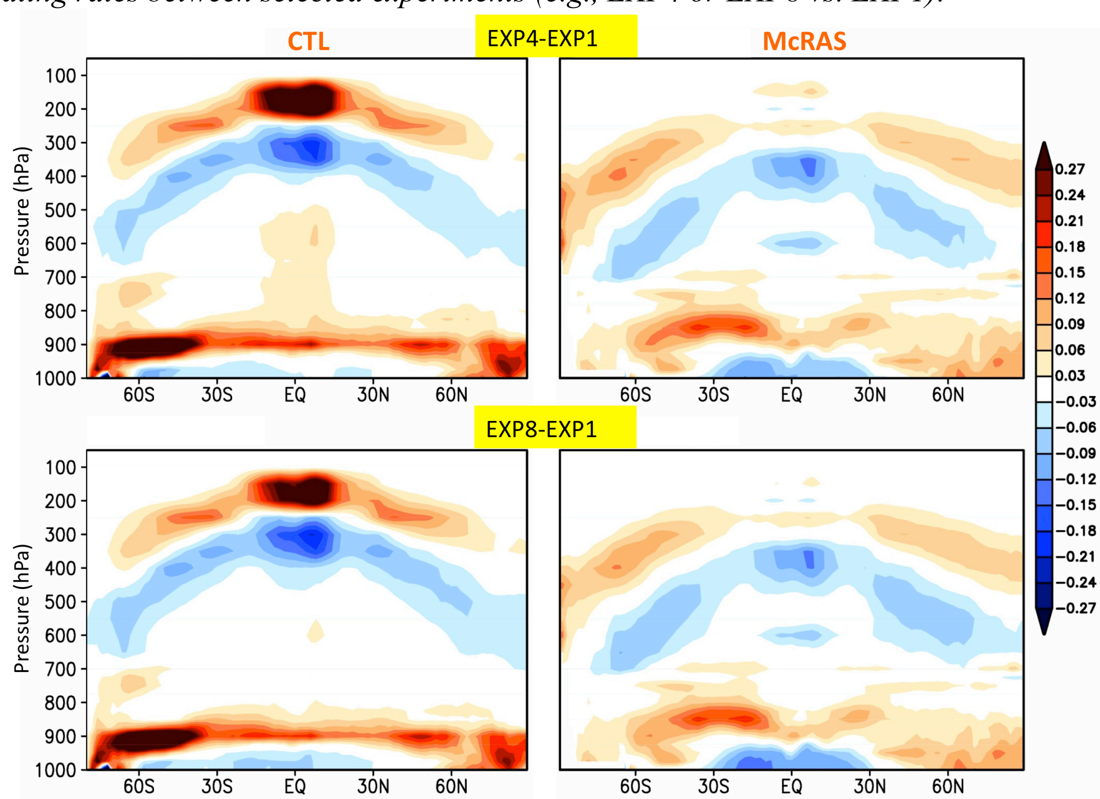
I find the sign convention used in Figs. 2, 3 and 4 counter-intuitive. If one has a reference case (REF) and several experiments (EXP) in which the model parameters are modified, the normal way of expressing the effect of the modifications would be as EXP-REF, not REF-EXP as apparently used here. Thus I strongly recommend to change the signs of the differences in Figs 2-4. This would also reduce the need for the now rather lengthy explanation of the sign convention on p. 12302. Another foolproof way of handling this would be to give the CRE values as they are, without subtracting the reference case.

This is why the specific sign convention was originally chosen: We wanted any CRE differences from observations (CERES-EBAF) of our anchor/reference (REF) experiment (Exp. 1) to be negative when the model indicated more radiative cooling or less heating. For excess SW CRE and inferior LW CRE to be negative we had to take the difference REF-OBS. Once this was established, the CREs from all other experiments had to also be subtracted from REF, thus REF-EXP was the natural choice. We don't think that by reversing the sign the discussion on the sign convention would have been reduced; in the end, similar explanations would have been neccessary. We therefore decided to adopt the "foolproof" (indeed!) recommendation of the reviewer and show actual CREs for the different experiments, not differences from REF. Figs. 2, 3, and 4 have been modified accordingly.

p. 12296, line 8: The assumption of horizontally homogeneous effective particle size should be discussed a bit more. Physically, it implies that horizontal variations in condensate amount result from variations in droplet/ice crystal number than their sizes. If there is a positive correlation between particle size and condensate amount (which at least aircraft observations tend to suggest) the radiative impact of subgridscale variability in condensate amount is reduced (Räisänen et al. 2003; Barker and Räisänen 2004).

We recognize this as a legitimate issue. We discuss this issue a bit more per the guidance above above and provide the appropriate references.

Would it be possible discuss how the assumptions on subgrid-scale cloud structure influence the radiative heating rates? E.g., represent a comparison between zonal mean heating rates between selected experiments (e.g., EXP4 or EXP8 vs. EXP1).



Effects on SW heating rates are very small (see also Räisänen et al., 2004). But there are indeed effects on LW heating rates. Since the paper is entirely focused on TOA CREs we elected to not show any heating rate results which are harder to interpret. We nevertheless show some results here, specifically differences between EXP1 and EXP4 & EXP8; units are K/day. Because LW heating rates are negative (i.e., they are cooling rates) essentially everywhere, positive values in the above figure indicate that EXP1 cooling rates are greater than EXP4 and EXP8 cooling rates and vice-versa. There are similarities in the difference patterns produced by the two cloud schemes. Moreover, the differences are very alike regardless of whether EXP4 or EXP8 is subtracted from EXP1. McRAS-AC overall shows smaller sensitivity, similarly to what transpires with CREs. The differences in the upper troposphere (peaking in the tropics for CTL, see also top panel of Fig. 9) are likely due to the additional shielding the greater cloud fraction of generalized overlap creates on the upwelling LW flux (less cooling in the case of generalized overlap). The flipside of this is larger cooling underneath due to the more cloudy upper troposphere being also a stronger emitter (note that the middle troposphere in CTL, especially in the tropics has very little cloudiness). A counterpart "dipole" pattern is also created in the lower troposphere for probably similar reasons. The peak magnitudes of the differences are slightly larger than Räisänen et al., 2004 (theirs are 0.18 K/day, ours are 0.27 K/day), but the comparison is not exactly apples to apples, given the different reference (theirs is ICA calculations).

In Fig. 11, does the lowest cloud fraction bin also include cloud-free cases? If yes, they should rather be separated from the cases with small but non-zero (0-0.05) cloud fraction. Completely cloud-free layers are irrelevant for cloud overlap.

No it does not. We have clarified this now in the caption.

Figure 12 suggests that completely cloud-free grid columns occur almost never, whichever cloud scheme is used. Is this the correct interpretation?

No, it is not the correct interpretation. The number of completely free cloud layers was actually not plotted in Fig. 12 whose abscissa actually started at "1", not "0". Incidentally, this query led us to revisit our calculations which led to the discovery of an error. The new figure is qualitatively the same, so our initial interpretation of the results stands, but reveals that many more instances of small number of cloudy layers coexisting occur. By adding minor tickmarks the ambiguity of the starting value of the abscissa is removed. Once again we chose to not include in the figure completely clear gridcolumns (zero cloudy layers) because their inclusion would stretch the ordinate too much. Clear gridcolumns is the most frequently state in the CTL cloud scheme, representing ~8.6% of January and ~7.9% of July gridcolumns (the numbers for McRAS are ~3% and ~2.3%, respectively).

TECHNICAL COMMENTS:
p. 12291, line 4: this should be "essentially"

Fixed.

p. 12291, lines 14-15: it is not clear what is meant by that the "McICA noise ... is of similar length ..."?

We meant magnitude. It's a mystery to as well how the word "length" creeped in.

p. 12293, line 15: this should be "may also be important"

Fixed.

p. 12294, Eq. (5): Am I right assuming that the mean value of the rank (i.e., the overbar quantities) is always 0.5?

Yes, if the original ranks R are normalized in [0.1] via $x=(R\text{-}1)/(\max(R)\text{-}1)$. We retain Eq. (5) as is because it is more general.

p. 12294, lines 4, 13 and 14: "Relative strength" seems like an odd wording in the case of condensate. "Relative magnitude?"

Changed as suggested (three occurrences).

p. 12297, fist line: remove the comma (,) before "potentially"

Done.

p. 12300, Eq. (12a): "all" might be a better notation than "cld" for a mixture of clear and cloudy skies.

Indeed. Changed.

In Table 2, it is not clear what is meant by "heterogeneous clouds" (you could refer to Eq. (9)). It is even less clear what is meant by "weaker cloud heterogeneity". This information can only be found on p. 12304, line 23. The tables should be self-explaining.

Point well-taken. We now refer to eq. (9) in the table entry corresponding to Exp. (2) and state explicitly that the standard deviation was halved for Exp. 5.

Fig. 1, in the first line of the caption, remove either the degree sign or the word"degree".

Fixed, removed the word "degree".

REFERENCES

Barker, H.W. and P. Räisänen, 2004: Neglect by GCMs of subgrid-scale horizontal variations in cloud droplet effective radius: A diagnostic radiative analysis. Quart. J. Roy. Meteor. Soc., 130, 1905–1920.

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