Response to Reviewers

I would like to the reviewer for the insightful and suggestive comments that helped us substantially improve the manuscript. Point-to-point replies to the comments are provided below (reviewer's comments in italic blue font).

This paper discusses the GCM sub-grid scale variability of cloud water content and droplet number observed by MODIS, and the consequences this variability has for autoconversion parametrization in GCMs. This has become a popular topic in recent years with many papers discussing the cloud water content variability, although the attempts to discuss droplet number variability are particularly novel and welcome in this study. The paper is well written and interesting. I have compiled a list of relatively minor comments or suggestions that the authors may wish to consider.

General comment –

the paper is very long, I'd encourage the authors to look for opportunities to be more concise in their descriptions and refrain from repetition of points.

Reply: The theoretical background part is longer than we hoped but necessary so the readers to understand the studies that followed. The length of the revised version is reduced by one page. It is not trivial considering that we extend the scope of the research significantly.

L57 - the reference here should be Boutle et al. (2014, QJ) not Boutle & Abel (2012)

Reply: we updated the references.

L60-62 - would be good to clarify a couple of things in these lines. Firstly, I think it would be better to refer to autoconversion and accretion "parametrizations" rather than "processes" - we shouldn't confuse the way we parametrize these things with physical reality, as there is not much overlap! Secondly, you should also clarify that you are ignoring variability in rain water content (qr) or Nc, as the nonlinearity of these (and correlations with qc) could strongly influence the result.

Reply: Agree, the KK2000 is simply a parameterization based on the least-square fitting to the LES results. We change the wording from "process" to "parameterization" throughout the text whenever appropriate.

We pointed out at the beginning of section 2.2 that we will only focus on the simulation of autoconversion while other processes such as accretion have been investigated in previous studies.

L92-95, 99-106 - this reads a little harshly on Boutle et al. (2014), who also used CloudSat data in their analysis to give a global perspective (and discussed the increase in variability from Sc to Cu and importance of co-variability on accretion). It might be worth mentioning the study of Hill et al. (2015, QJ) here as well, who extended this work to explicitly build in the regime dependence to the parametrizations. Also there is a typo on L104/5, which should say "cloud water variance is larger over the Cu region than over the Sc region".

Reply: Agree, we revised the discussion, added the Hill et al. (2015) and also corrected the typo.

L117-118 - again, might be good to clarify here - Boutle et al. (2014) and Lebsock et al. (2013) discuss the variation in rain water (which is distinct from cloud water). But you are correct that I'm also unaware of any studies looking at CDNC variability.

Reply: Following your suggestion, we pointed out again that *Boutle et al. (2014) and Lebsock et al. (2013)* have investigated the variation of subgrid cloud water as well as rain water.

L194 - would be good to clarify here - it's not the LES that was important in KK2000, but the fact that they used a bin-resolved microphysics scheme, which accurately represented the physical processes of collision-coalescence, to derive the simple parametrizations

Reply: Agree. In the revised version, we pointed out after the introduction of KK2000 parameterization scheme that the KK2000 is "derived through a least-square fitting of the autoconversion rate results from a large-eddy simulation with bin microphysics that can simulate the process-level physics."

Figure 1d - I cannot see this referred to at all in the text, yet it shows something interesting/puzzling to me, namely a significantly different CDF of rain rate for the gamma and lognormal distributions of CDNC - can you explain why this is?

Reply: As shown in Figure 1, provided the same mean value and same inverse relative variance v, the lognormal distribution $P_L(x)$ is generally larger than the Gamma distribution $P_G(x)$. The difference is clearly visible when $x > 2.0$ in Figure 1 b. This differences in PDF gives rise to the difference in the CDF of autoconversion rate.

L256-260 - I'd always thought part of the argument for ignoring Nc is that its value is typically linked to the underlying aerosol distribution, which varies on much larger spatial scales than qc, therefore the amount of Nc variability that would be 'sub-grid' is expected to be small/negligible.

Reply: Aerosol loading is only on part of the story. CDNC is not only determined by aerosol loading but also critically be the subgrid turbulence (i.e., updraft). Many previous studies have pointed out the importance of subgrid variations of updrafts in simulating cloud microphysics in GCM (e.g., (Morales and Nenes, 2010)). However, most GCMs lack the capability of simulating the subgrid variations of updrafts until very recently the advanced parameterization schemes, such as CLUBB and MMF, became available.

L274 - please define CER as this has not been previously defined

Reply: It is clarified.

L278 - brackets should be around the years only of Platnick et al. (2013,2017)

Reply: Corrected.

L344 - I'd say the current generation of GCMs are those being used for CMIP6, so perhaps update this and the reference (although 1x1degree still doesn't seem unreasonable for what many models are running)

Reply: Updated and added the new reference (Eyring et al., 2016)

L372 - should say "dominant" cloud types

Reply: Changed.

L450 - I think there is something missing from this sentence - "this approach is more although it may be..."

Reply: It should be more "efficient". Corrected.

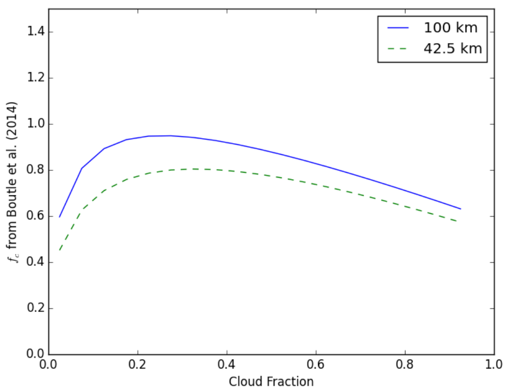
Figure 6d - does not appear to be referred to in the text. It should either be discussed why it is relevant, or not shown.

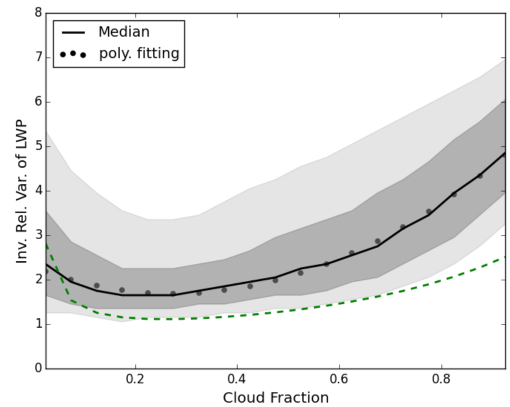
Reply: It is removed. Thanks for catching this.

L487-501 - given there is already a parametrization of v(f_liq) in existence, namely that of Boutle et al. (2014), it would be interesting and very easy to see how well their parametrization compares to the independent MODIS dataset generated in this study.

It's probably too much work to investigate the Hill et al (2015) parametrization as that would require a way of determining from MODIS whether cloud is convective or not, but that would also be interesting.

Reply: We first replicate the Figure 4 in Boutle et al. (2014) to confirm our code works consistently with the original result.





Then, we compared the parameterization scheme from *Boutle et al. (2014)* for grid size ~ 100km to out Figure 7a (the green dashed line). Apparently, there are some differences between the two especially for large cloud fraction, probably because the two studies are based on different data. Since the difference between the two studies are out of the scope of this paper. These figures are not shown in the paper.

L506-516 - it would also be worth noting that these fits are only applicable to a single model resolution, and so not as useful as existing parametrizations with inbuilt scale adaptiveness.

Reply: Agree and we already mentioned that this parameterization is only valid for 1x1 degree model resolution when we list the important limitation of this study.

L559 - there is reference to supplementary materials, yet I cannot find any?

Reply: We originally planned to add the seasonal plots (e.g., DJF and JJA) in the supplementary materials, but we found that seasonal plots do not really add any additional insights. So, we simply removed them. Sorry for the confusion.

Boutle, I. A., Abel, S. J., Hill, P. G. and Morcrette, C. J.: Spatial variability of liquid cloud and rain: observations and microphysical effects, Quarterly Journal of the Royal Meteorological Society, 140(679), 583–594, doi:10.1002/qj.2140, 2014.

Reference:

Boutle, I. A., Abel, S. J., Hill, P. G. and Morcrette, C. J.: Spatial variability of liquid cloud and rain: observations and microphysical effects, Quarterly Journal of the Royal Meteorological Society, 140(679), 583–594, doi:10.1002/qj.2140, 2014.

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J. and Taylor, K. E.: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, Geosci. Model Dev., 9(5), 1937–1958, doi:10.5194/gmd-9-1937-2016, 2016.

Morales, R. and Nenes, A.: Characteristic updrafts for computing distribution-averaged cloud droplet number and stratocumulus cloud properties, J. Geophys. Res., 115(D18), 1227, 2010.