Response to Short Comment on acp-2016-831

Dear Dr. Karsten Peters,

Thank you very much for posting the insightful and important comments on the discussion forum.
I am returning herewith a manuscript revised according to the comments.

[SC]: Short comment in *Italic*
[AC]: Author comment

Short Comment:

[SC] *In their submitted contribution to ACP, the authors investigate the reasons behind the discrepanies in cloud and precipitation response to changes in the number of cloud droplets* dN_C *in observations (satellite) and an aerosol climate model (MIROC-SPRINTARS). By doing so, the cloud and precipitation response under conditions of changing aerosol concentrations is investigated (if a positive relationship between* dN_C *and increasing aerosol concentrations is taken for granted). Overall, the authors find that the modelled sensitivity of cloud and precipitation responses to* dN_C *are in disagreement with observations and that this disagreement most probably stems from the simplistic parameterization of autoconversion in the model. This has been known for quite some time now (see references in the submitted manuscript), therefore rendering the submission as yet another study showing the limitations of current generation aerosol-climate models to adequately reproduce observed aerosol-cloud interactions. The limitations of satellite observations for this purpose must also be kept in mind though. Unfortunately, the authors miss the opportunity to present at least some suggestions for future model improvements, which - given the wealth of data and diagnostics presented - would add significant punch to the submission.*

In light of the above, I find the global distributions of $d \ln LWP / d \ln N_C$ *shown in Figure 2c,d of the submitted manuscript very intriguing and investigating the shown relationships further would potentially add more substance to the science presented.*

Although the magnitude and even the sign of the shown relationships in Fig. 2 differ significantly between observations and the model, the overall pattern is similar: the relationship becomes weaker towards the tropics - although still of wrong sign. The reason for this could be high natural variability and the dominance of cloud dynamical processes compared to microphysical ones (e.g. Peters et al. (2014)). The same processes could be at work in the model used in the present study.

From the model description presented in the manuscript, it appears that the prognostic cloud scheme used in MIROC-SPRINTARS accounts for subgrid-scale variability of clouds. If possible, it would be very interesting to investigate the response of cloud properties to dN_C *as a function of subgrid-scale variability as diagnosed in the cloud scheme. If there does exist a systematic relationship between cloud subgrid-scale variability and the cloud response to* dN_C *in the model, such an analysis could provide important insights into the model physics and provide useful suggestions for improving the parameterisation of cloud microphysics.*

[AC] We would like to thank Dr. Karsten Peters for very insightful comments and suggestions for improving our manuscript.

Although Fig. 2a does not indicate a regional dependence of LWP responses clearly, Fig. 2c indeed shows the similar pattern of LWP-susceptibility to observations, that is, the relationship becomes weaker towards the tropics. One of the possible mechanisms is the dominance of cloud dynamical processes rather than microphysical modifications due to aerosol perturbations (Peters et al., 2011, 2014), hence it might be related to the handling of the subgrid-scale variability in the model.

Here we show the geographical distribution of PDF moments (variance and skewness) for total water content prognosed in MIROC (Fig. R1). This suggests that the spatial gradients of both variance and skewness are larger in precipitating conditions (Figs. R1c and R1d) than in non-precipitating cases (Figs. R1a and R1b). The regions over tropics and subtropics where cumulus (inhomogeneous cloud) is dominant, show larger variance and strong positive skewness mainly due to the convective detrainment and/or dry air advection. These regions reasonably correspond to the area where LWP-susceptibility is relatively weaker. However, this is not always true particularly in non-precipitating cases, so we must interpret carefully the mechanisms with further analysis, which is beyond the scope of this paper.

For example, the spatial gradient of LWP and N_c with different meteorology could also incur the spurious correlation of LWP-susceptibility due to their covariance (e.g., Grandey and Stier, 2010; Gryspeerdt et al., 2014). Alternatively, biases in cloud geometric thickness (i.e., dependence on vertical resolution) could cause fluctuations of the modeled LWP-susceptibility as well.

These obscures from the several possibilities mentioned above need to be clarified. This will require more detailed examinations of resolution dependence, regional characteristics using observations, and also some further sensitivity experiments in the PDF parameterization. Hence only limited materials are shown at this stage, and this issue will be investigated in future work.

We add some discussion about 1) a relationship between cloud subgrid-scale variability and modeled LWP-susceptibility and 2) future model improvements, according to the comments.

1) relationship between cloud subgrid-scale variability and modeled LWP-susceptibility

The following paragraph has been inserted in Section 3.2:

Page 7 Line 8–14: "Nevertheless, it should be noted that Fig. 2c captures the horizontal distribution of LWP-susceptibility, whose pattern is very similar to observations. That is, the relationship becomes weaker towards the tropics, although the sign is still different. One of the possible mechanisms is the dominance of cloud dynamical processes with high natural variability over tropical/subtropical oceans rather than microphysical modifications by aerosols (Peters et al., 2011, 2014). The same processes observed from satellites could be at work in the model, and hence it might be related to the parameterization of subgrid-scale variability. However, this is not always true particularly in non-precipitating cases (Fig. 2a), so we must interpret the mechanisms carefully with further analysis in future."

2) future model improvements

We believe that one of the most important future model developments is an introduction of prognostic precipitation framework in GCMs (e.g., Sant et al., 2015; Gettelman et al., 2015), as described in the discussion paper (Page 9, Line 4–17). In addition to this, the importance of the parameterization of subgrid-scale variability has been added in the revised manuscript as follows:

Page 10 Line 25–35: "Furthermore, a representation of subgrid-scale fluctuations has also been a critical problem in GCMs. Although the magnitude as well as sign of LWP-susceptibility differs between the model and observations, the horizontal pattern is similar in precipitating conditions. The parameterization of subgrid-scale variability may partly contribute to weaken the aerosol roles by capturing the large natural variability of clouds especially over tropical/subtropical oceans (Peters et al., 2011, 2014), which would lead to more realistic representation of cloud dynamical processes. For example, Guo et al. (2011, 2015) showed that both positive and negative LWP responses can be represented in even a GCM framework, by the PDF-based subgrid parameterization, called "Cloud Layers Unified By Binormals (CLUBB; Larson and Golaz, 2005)". Lebsock et al. (2013) estimated a weighting factor of process rate equations to consider the subgrid effects based on A-Train retrievals unless accretion process is significantly underestimated. The interaction between microphysics and subgrid-scale dynamics (microphysics–dynamics interactions) in GCMs is therefore one of the indispensable processes for incorporating buffering effects and for improving model physics as a whole."

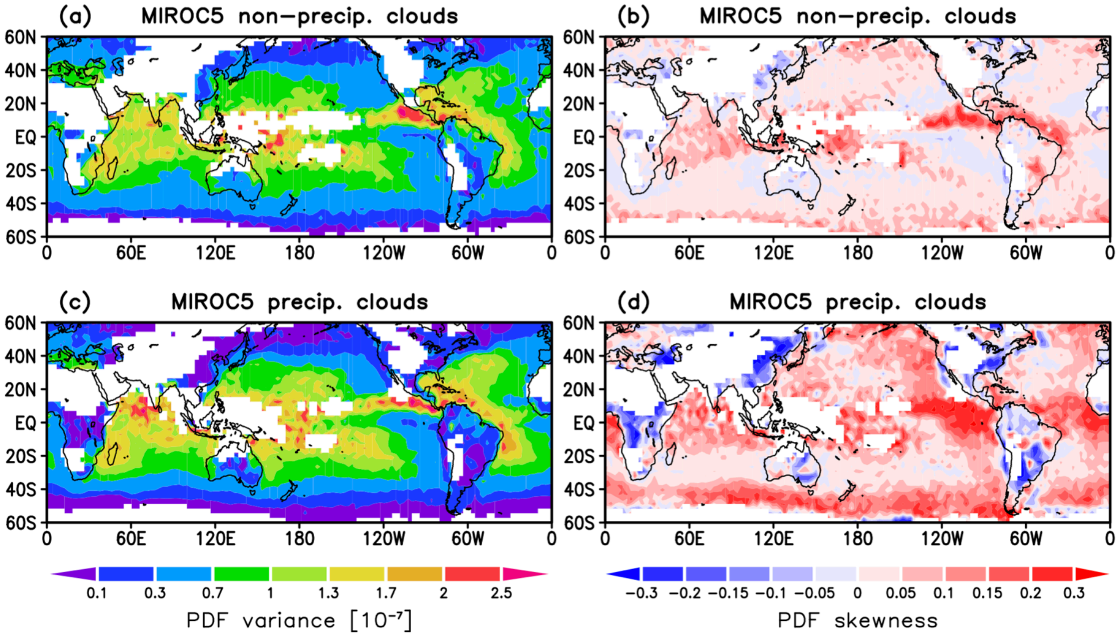

Figure R1. Global distribution of PDF moments for total water content (at the cloud mid-level) prognosed in the MIROC-SPRINTARS subgrid scheme. (a, c) PDF variance and (b, d) PDF skewness are displayed for both non-precipitating and precipitating cases.

Thank you very much for insightful discussion and valuable comment for our paper.

Sincerely yours,

Takuro Michibata

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