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Atmospheric
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Discussions

Interactive comment on "Does the threshold representation associated with the autoconversion process matter?" *by* H. Guo et al.

H. Guo et al.

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The reviewers and editor are thanked for the comments and perspectives, which have proved to be a valuable guide. We greatly appreciate the generally positive comments from both reviewers, and have addressed all of them item by item. Our responses have also been posted online (http://www.cosis.net/members/journals/df/article.php?paper=acpd-7-16055).

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Summary:
This paper addresses, within the framework of a high-resolution eddy resolving cloud model of stratocumulus, whether the model's cloud cover, liquid water path, and

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aerosol indirect effectare sensitive to whether the autoconversion has a strong threshold function. To do this, the authors use a previous theoretical relationship between the threshold function T and the dispersion of the cloud droplet size distribution and then vary the assumed dispersion to vary the nature of T. I think the model results are useful in highlighting that the thresholding function can have a major impact upon the autoconversion rates and therefore the aerosol indirect effects in the model. This is an important finding and one with relevance to a broad audience. The manuscript is worthy of publication in ACP subject to some issues I discuss below.

Comments

1. The authors should be careful to make clear that the effect of dispersion being explored here is upon the threshold function not upon its impact upon the rate term P_0*. In the manuscript as it stands this is only emphasized at the end. The use of a threshold function itself makes sense because the autoconversion construct itself has an implicit threshold, autoconversion being the rate of flow of mass by coalescence across a particular droplet size threshold. For a monodisperse size distribution there will be no autoconversion unless the droplet resulting from collisions between two droplets exceeds the size threshold (typically a radius threshold of 20-25 microns is used). Thus, in this case, a step function form of T would be appropriate. For a broad size distribution on the other hand, the threshold function would be expected to be much smoother. Thus, the type of threshold function is strongly tied to the assumed dispersion, which the authors use to determine T. The effect upon the rate term is not explored here.*

A: The reviewer is right. The dispersion effect on the rate term P_0 is not explored in this paper because the purpose of this study is to examine whether or not different threshold representations have significant effects on model results.

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We will add 1 short paragraph at the end of **Sect. 4.1** on **P. 16061**:

"It is noteworthy that ε also influences the rate function P_0 in Eq. (1). [Note: $P_0 = \kappa \frac{(1+3\varepsilon^2)(1+4\varepsilon^2)(1+5\varepsilon^2)}{(1+\varepsilon^2)(1+2\varepsilon^2)} N_d^{-1} LWC^3$, Eq. (8) of Liu et al., 2006b]. However, in order to isolate the dispersion effect on the threshold function, in this study the values of ε are set to be 0.1 and 0.2 for the calculations of P_0 in the "CLEAN" and "POLL" cases, respectively, (according to the observational study by Pawlowska et al., 2006).

2. The results demonstrate that the choice of threshold function is important (comparing an assumed dispersion of 0.4 with a monodisperse size distribution makes a big difference to the AIE). However, the range of dispersion used is enormous, with only values 0.1-0.4 being appropriate in the parts of clouds in which autoconversion matters (high liquid water contents rather than in decaying evaporating parts of the cloud). In my view, comparing with a monodisperse size distribution serves to demonstrate just how inadequate the Kessler-type thresholding really is. Further, doesn't the comparison of a dispersion of 0.4 with a dispersion of infinity (differences between red and green dots in Fig. 1) suggest that it might be better to disregard the threshold function altogether (i.e. assume T=1)? Would it not be more useful to compare a dispersion of 0.1 and 0.4 rather than infinity with 0.4 and zero with 0.4? In other words, the use of a threshold function may only be important when the autoconversion rate is very low and therefore irrelevant for the formation of precipitation needed to significantly affect LWP and therefore produce a significant second (i.e. feedback) AIE. The results of Wood (2005, Fig 4) clearly demonstrate that unless the autoconversion rate (derived by applying the stochastic collection equation (SCE) to observed size distributions in polluted and clean clouds) is lower than approximately $10^{-9} kgm^{-3}s^{-1}$ *(i.e. less than* $0.1 gkg^{-1}day^{-1}$ *of drizzle production!) then the basic analytical rate function of Liu and Daum (2004) is an adequate descriptor of the autoconversion rate(subject to modification by a constant factor as discussed in Wood and Blossey 2005)). Unless I missed it the authors should state what rate function* P_0 *they are using. From Guo et al. (2007) it* *appears to be the Liu and Daum formulation which tests very well against observations.*

A: We agree that only values 0.1-0.4 of the dispersion (ε) are appropriate in the ambient clouds in which autoconversion matters.

However, this paper is aimed at model development. Strikingly different threshold functions, ranging from the Kessler-type (ε = 0) to the Sundqvist-type (ε = 0.4) and to the Berry-type ($\varepsilon = \infty$) threshold functions, have been used arbitrarily in modelling studies. For example, Pawlowska and Brenguier, (JGR, 2003) combined the autoconversion scheme developed by curve-fitting simulations of an explicit microphysical model (Khairoutdinov and Kogan, MWR, 2000, hereafter KK00) with the Kessler-type threshold function to calculate the autoconversion rate and compare it with observations, whereas in other studies (including KK00), the curve-fitting equation is directly used without threshold, which is equivalent to assuming T = 1. In this study, we have conducted sensitivity tests for ε = 0, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 10.0, and 300, and compared the results for ε = 0 with those for ε = 0.4, and for ε = 0 with ε = 300 to cover the whole range of threshold functions that have been used in practice.

The comparison of ε = 0.4 with $\varepsilon = \infty$ (differences between red and green dots in Fig. 1) does NOT suggest that it might be better to disregard the threshold function altogether, because this comparison only illustrates the sensitivities of the model results to different threshold functions determined by ε.

As shown in Eq. (1), the autoconversion rate (P) is the product of the rate function (P_0) and the threshold function (T, $0 \leq T \leq 1$). For efficiently drizzling clouds (which often imply

$T = 1$), the magnitude of P equals to the magnitude of P_0. So P_0 is an adequate descriptor of P.

As shown in Eq. (2), T depends on both ε and x_c. When x_c is ~ 1, T could change dramatically from 0 to 1 (or vice versa) depending on ε [Fig. 1 of Liu et al., (GRL, 2006a)]. This would initiate (or suppress) precipitation and be relevant for the estimate of the 2nd aerosol indirect effect. As shown in Figs. 1 and 3 in this manuscript the AIE could differ significantly (as much as $\sim$ 100%).

Yes, the rate function P_0 is calculated following the Liu and Daum (JAS, 2004) scheme, i.e., $P_0 = \kappa \frac{(1+3\varepsilon^2)(1+4\varepsilon^2)(1+5\varepsilon^2)}{(1+\varepsilon^2)(1+2\varepsilon^2)} N_d^{-1} LWC^3$, which is also presented in our reply to comment #1.

3. A general comment on the use of the threshold function T: It is straightforward in principle to calculate the autoconversion rate by integrating over both the collector and collected drop, with the limits of the inner integral being a function of the outer variable (see Beheng and Doms 1986, for example). If one could solve the autoconversion integral analytically for an arbitrary cloud droplet size distribution then there would be absolutely no need for a separation between the rate and the thresholding functions (i.e. P and T) at all. So the use of a threshold function comes about because the approximate formulations of the autoconversion integral that are used (e.g. the work of Liu and coauthors cited in this work) are problematic because they are evaluating a different integral. The integral being evaluated is one in which the integral‘s limits permit any coalescence event between droplets to be counted as contributing to the autoconversion rate regardless of whether the collision passes the threshold radius. Unfortunately, this integral is not the autoconversion rate. This issue is discussed in Wood and Blossey (2005).

It is my opinion therefore that the theoretical work in this area is therefore not yet *complete because the effect of dispersion is split unphysically between T and* P_0*. This is not very satisfactory from a theoretical standpoint. As such, I am a little suspicious about the general applicability of Equation (2) in the current work. Comparisons between numerical evaluations of the true autoconversion integral and the analytical thresholded expressions for realistic size distributions would be helpful. Such evaluations are beyond the present work but would be useful nonetheless. I would be happy to discuss any of these issues with the authors directly.*

A: We generally agree that it is useful to compare numerical evaluations of the true autoconversion integral with the analytical results for realistic size distributions, and that the dispersion affects both the rate function (P_0) and the threshold function (T). However, as mentioned by the referee, too much discussion of the theoretical studies of P_0, T, and comparisons between the true autoconversion integral and analytical expressions would deviate from the focus of this study. We would be happy to discuss any of these issues with the referee directly.

Anonymous Referee 2

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This is a well-designed study of the sensitivity of simulated clouds to the treatment of the autoconversion of cloud water to precipitation. A physically-based treatment expresses authoconversion in terms of two parameters: the droplet dispersion and the critical radius for autoconversion. Although the instantaneous cloud fraction, liquid water path and aerosol indirect effect exhibit significant sensitivity to the treatment of autoconversion, the time mean over a day is much less sensitive except with unrealistically large values of the critical radius. The presentation is compact and clear, with only a small amount of further explanation required.

Comments

1. How much of the sensitivity of AIE is due to the dependence of autoconversion on dispersion and how much is due to the dependence of cloud optical depth on dispersion?

A: Both the autoconversion and cloud optical depth (COD) are dependent on the cloud droplet dispersion, and they influence the estimate of aerosol indirect effect (AIE). However, it is not trivial to separate the sensitivity of AIE to the dispersion dependence of autoconversion from that of COD. This is because the autoconversion and the COD are correlated with each other. For example, COD depends on cloud liquid water path (LWP) and the LWP depends on autoconversion process. On the other hand, the COD influences radiative cooling/heating, and then the LWP and the autoconversion.

2. Figure 3 caption. Change ration to ratio?

A: This will be corrected.

3. Figure 4. Why is x_c larger for the polluted case?

A: The value of x_c is an increasing function of cloud droplet number concentration (N_d) but a decreasing function of liquid water content (LWC) [$x_c \sim N_d^{3/2} LWC^{-2}$, Eq. (12) of Liu et al., (2005)]. In the “POLL” case, x_c is larger because the N_d is larger and the LWC is smaller. We will add the explanation in the 3rd paragraph on P. 16060.

4. Page 8, third paragraph. The entrainment drying explanation has also been identified by Ackerman et al. (Nature 2004) and by Bretherton et al. (GRL 2007).

A: We will add the references by Ackerman et al. (Nature 2004) and by Bretherton et al. (GRL 2007).

5. Page 8, lines 23-27. Alternately, one might conclude from this that using a 10 micron critical radius is sufficient in the time mean.

A: In cloud resolving models, the critical radius (r_c) is typically set to be 10 μm; but in global climate models, r_c may vary from 4.5 to 7.5 μm. However, these specifications of r_c in models are often empirical and lack of a sound physical basis. In our cases, a 10 μm critical radius is sufficient in the time mean, but it does not necessarily mean that this would universally hold true.

6. Page 8, last two lines. A value of 20 microns for the critical radius is unrealistic, so

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why present it?

A: We want our sensitivity tests covering a wider range of the prescribed critical radius than is typically observed, so that the full sensitivity of the results can be explored.

7. Page 8. Are these conclusions any different for the polluted case, which exhibited greater sensitivity to dispersion than the clean case does? Is there any evidence that a fixed 10 micron critical radius produces bias in any results other than at small scales?

A: In the polluted case, cloud droplet volume-mean radius is much smaller than that in the clean case (4 μm vs. 8 μm). The autoconversion process is less efficient in converting cloud water to rain water, and thereby there is only a small amount of drizzle production, which is also consistent with the observations. If we artificially further increase the prescribed r_c (say, 15 μm), the autoconversion rate and the drizzle rate are virtually zero and would not be influenced by the prescribed r_c significantly. So the simulated cloud properties would become less sensitive to r_c if the autoconversion rate is (already) so small so as to be neglected.

In our study, the sensitivity test with a fixed 10 μm critical radius produced different instantaneous cloud fields (e.g., cloud liquid water path) at smaller scales, as compared to larger scales. But for the averaged fields, the results are expected to be similar.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 16055, 2007.

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