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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Analytical treatment of ice sublimation and test of sublimation parameterisations in two-moment ice microphysics models" *by* K. Gierens and S. Bretl

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Reply to reviewer's comments on ms acp-2009-83

1 Review No. 1

1.1 Ad General comments

We have added a new first paragraph in the introduction comparing the strenghts and weaknesses of bulk vs. bin models. We have additionally quoted some more recent

papers that describe or use bin models.

Of course we agree that bin models are more exact than bulk models, however, as long as we do not have much faster computers, there will be applications that require the application of bulk microphysics. To our view this is completely ok, as long as we know how far we can go with these models and where the limits are beyond of which the results become doubtful. The present paper intends to provide such a test, and in fact the test presented in sect. 5.5 was not just an academic exercise; it resulted from a doubtful phenomenon that we noticed in some of our simulations.

1.2 Ad Specific comments

Page 2, Fig. 1: The quoted value of a (0.004) occurs at about 98% RH_i at -50 °C and 250 hPa. Other parameter combinations can lead to a similar value of a.
Page 2, end of chapter 2: Although we do not treat growth cases here, we deem it worth to mention that the shape of the spectrum changes only little when $a > 0$.

Page 3, Fig. 2: There are four curves and they are nearly identical. The figure caption has been improved.
Fig. 3, Fig. 4: arrows added. The curves are computed for $a = 0.004$, similar to those in Fig. 1. This is not really relevant, since it does not affect the shape of the curves.

Page 4, text referring to Fig. 5: It is just the idea of introducing the dimensionless time τ to unifiy all these curves. If we choose another pair of (m_0, a), we end up with a different time transformation (i.e. the definition of τ changes), such that h retains its shape. The shape of $h(\tau)$ changes however, once another underlying mass spectrum or a different σ_m is chosen. We give an example now in the text. As m_0 is not the biggest mass in the crystal ensemble but a typical mass (e.g. the mean), there are crystals bigger than m_0 and they need more time to sublimate, hence $\tau > 1$. The text has been extended and hopefully improved.

Page 4, right column: The text has been clarified.

Page 5, left column: This text has been deleted from the revised version.

Page 5, denominator: Corrected.

Page 6: Meaning of q_c and N included.

Equation for RH_i: The initial conditions for this experiment are chosen such that when the ice mass is completely sublimated we get 105% RH_i. The units of RH_i and the other terms in the equation are percent, as indicated. The text has been improved.

Page 6, right col., par. 5: In fact, the reference results have been obtained with a bin model. As stated, we use a numerical procedure where we solve the sublimimation and growth equations for a size distribution represented by 1000 discrete initial masses (this is a bin model with moving grid).

Marshall–Palmer: Agreed. As the M.P. distribution is an exponential distribution, we just use the latter expression.

Final general comments: have been added at the very end of the paper.

2 Review No. 2

Note: This Review was already made in the technical review phase. It did therefore not appear in the Discussion web pages. For the convenience of the reader we copied the comments and give the replies below each of them.

Major Comments

1. P.2, Solution for $f(m,t)$
I wonder why the transformation to coordinate x is done. Eq. (3) follows straight for-

ward from the solution given in Appendix B for $a =$ const. The statement "... shape of $g(x,t)$ does not change over time.. " is trivially fulfilled for $a =$ const. and does not need a proof. On the other hand, Appendix B does not actually inform on the derivation of the solution. The derivation of the solution of (1) for drop condensation/evaporation is given in e.g., Y.S. Sedunov (1974): Physics of drop formation in the atmosphere. John Wiley & Sons, New York. The notation of absolute values of $dm(0)/dm(t)$ is not required, since $dm(0)$ and $dm(t)$ always have the same sign for the assumed growth rate (2).
Reply: The solution given in Appendix B (now A) is more difficult to apply than the solution derived in the main part of the text. It is only presented as a slight generalisation that might be useful for some readers. The transformation to the variable x is not really necessary, but it makes it easier to follow the derivation. We agree that Appendix A is not necessary and we drop it. The work of Sedunov is now quoted in the Appendix. The absolute signs are required, since $dm(0)/dm(t)$ can become negative if $A(t)$ is positive (for growth; for sublimation you are correct. See the last equation). This generality should be retained. The dm are differentials and not growth rates.

2. Section 3
The introduction of the Φ_k and f_k seems to be a crucial and a new idea in the parameterisation. Improve the presentation of definition and interpretation. While $f_k(t,\Delta t)$ is defined for a single time step, the interpretation suggests something different. The whole section should be revised for clarity.
Reply: We have changed the description of $f(t,\Delta t)$ and hope that the new text is clearer.

$\tilde{\alpha}$**?**
Reply: As stated, a fit parameter.

Why $f'_k = I_k^{-1} dI_k/dt$?
Reply: We write the equation with a bit more detail in order to clarify. It can simply be derived by Taylor expanding f_k with respect to Δt and Taylor expanding $I_k(t+\Delta t)$

around t, and neglecting higher than first orders of Δt.

Eq. for $\partial f/\partial t$ at the end of the section requires explanation.
Reply: Admittedly, to actually compute this derivative (from eq. 3, old counting) is a bit lengthy and prone to errors, but it is straightforward and does not need more explanation. It is simply a derivative.

Figure 3: How can time run along each curve, if f_k is defined for single Δt? Does time really run "... from bottom right to top left.."? What are $x, f(x)$?
Reply: Time can run along the curves since we plotted consecutively the pairs (f_m, f_n) for series of sublimation timesteps. These pairs are marked along each curve. The text of the caption has been changed, $x, f(x)$ have been replaced.

3. Section 4:
The introduction of the time scale is interesting, yet the presentation can be improved. Interpretation of $h(\tau)$? How does τ enter the right hand side of the definition equation for h? I can see only 2 lines in Figure 5, but the text refers to others. What is τ_0?
Reply: We have extended the interpretation of $h(\tau)$ by adding text that descibes in more detail what we see in the figure. We have corrected and extended the right hand side of the definition equation for h. The figure appears to show only two lines because the different curves are nearly congruent. We have added a statement of this in the caption.

4. Likewise, Section 5 should be revised for clarity. I mention only 2 examples: The beginning is abrupt. Please establish the relation to the previous sections.
Reply: We have added two short paragraphs at the beginning of Sect. 5 that should establish a bridge to the foregoing sections.

p.5 r, last equation: The solution is not generally valid, but only for a specific analytic function $f(m)$.
Reply: This is correct. We have added a piece of text stating that this is the truncated moment for a log–normal distribution.

5. There seems to be a break between Sections 2, 3 and Section 5. Please work out how the tests are based on the preceeding derivation of the solution $f(m,t)$ etc. The discussion of the tests reads like a work report, but could be done more stringent.
Reply: The tests are simply based on one benchmark, namely the function $\phi_n(\phi_m)$ obtained from the analytical solution in Sect. 2. There was already text stating this. This text has been slightly extended and shifted in the introductory subsection of section 5. Of course, this is somehow a work report (we actually did the tests), and we found not much that can be dropped without leaving the reader "alone". Of course one might summarise the tests saying that other formulations do not work better than the simple power law. This is our message. But we think that readers might want to see more details in particular if someone is interested to make further tests. So, we have only shortend the second paragraph in 5.1.

p.6l, middle: Why does $f_n \propto f_m$ not fulfil the boundary conditions if $f_n \propto f_m^\alpha$ does for $\alpha > 1$ and $\alpha < 1$?
Reply: Proportionality means: $f_n = cf_m$. Hence, the boundary conditions are only fulfilled if $c = 1$ which cannot be taken for granted. We use now this formulation instead of $f_n \propto f_m$. Text was also slightly corrected.

6. Figures: Please precise all captions, descriptions, and interpretations. Specify formulations like "... for various initial conditions ..." , in particular if only 1 line is plotted.
Reply: In figures 2, 5, and 6, we have the plotted curves for various conditions, but only one curve can be seen, because the differences between the curves are smaller than the curve thickness; the curves are nearly congruent. Therefore, the exact conditions are unimportant. We note the congruence of the curves now in the figure captions in order to prevent confusion.

Minor Comments

1. Number all equations.
Reply: Done.

2. Please add a list of symbols.
Reply: Done.

3. p.1l, line 4-6: What does it mean "... affect only indirectly..."? Number density is affected by sublimation, if the particle mass shrinks below the threshold value. Otherwise it is not affected.
Reply: We agree. The formulation has been changed.

4. p.1r: Please improve the introduction of the 1st equation.
Reply: We have added a couple of sentences and hope the result is better. We cannot give a complete derivation of the equation, which would need too much space.

5. p.7l, para 3: I do not understand the discussion of σ_m = const. This is an assumption. The analytical solution (3) is based on that, hence any "consistency with the analytical solution" is not to be questioned. If an additional moment is forecasted, the whole model would be different. Please explain.
Reply: We decided to delete this paragraph completely.

6. Please check your terminology. Examples:
Is $f(m)$ really a "probability"? p.2l, line1, and middle of App. B: Where is the "randomness" in your model?
Reply: As crystals in a cloud have usually differing sizes, most bulk cloud models assume an underlying size (or mass) distribution. Mathematically this is equivalent to a probability density (apart from normalisation). See new text in section 2.

p.4r: Why distinction median - geometric mean if equal anyway?
Reply: Actually, it does not matter whether m_0 is the median mass or the mean mass.

It is a characteristic mass of the distribution $f(m)$ which can be the median, the mean, the mode, or something similar. We have changed the wording in Section 4 accordingly.

p.4r: Definition of τ_0?
Reply: The definition of τ_0 is given in the first sentence after the equation. A physical interpretation is given several lines later.

Eq.(2) and text: Why should m be dimensionless? $dim(a) = dim(m)^{1-b}/Time$, so why is m not allowed to have the dimension of mass. If you choose indeed m to dimensionless, give its correct definition and avoid values of m in e.g., ng.
Reply: It is an old unfortunate habit of cloud physicists to write their empirical relations in a way that properly requires dimensionless quantities (expressions like m^b otherwise make no sense, there is simply no such thing as kg$^{0.357}$). In the revised version we resort to a new notation. Instead of

$$\dot{m} = am^b$$

we write

$$\left(\frac{\dot{m}}{UM/UT}\right) = a\left(\frac{m}{UM}\right)^b,$$

where UM and UT are explicitely mass and time units. Later in the equations we drop the reference to the units (but have them still in mind). This allows then to let m have the dimension of a mass, while a and b are pure numbers. The figure captions have been updated, accordingly.

p.1r: "spectral growth equation"??
Reply: Changed into "spectral form of the equation for deposition/sublimation".

p.3l: What do you mean, Φ_1 or Φ_m? Φ_0 or Φ_n? Please harmonise.
Reply: We have two "boundary conditions" here: 1st, the expression using the moments needs a numerical index, but 2nd, the quoted papers use the literal indices m and n. Although we do not believe that this interchangeable usage causes great difficulties for the reader we have added a note in section 3.