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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Introduction of prognostic rain in ECHAM5: design and Single Column Model simulations" *by* R. Posselt and U. Lohmann

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The authors wish to thank the referee for the comments helping with the revision of this manuscript. Three of the four main problems have been be fully addressed as described below. The implementation of a more appropriate sedimentation scheme is work in progress and, thus, will be addressed in future.
Below please find a point by point response to your comments.

Reply to "General comments":

- Explicit numerical sedimentation scheme: As described in the paper the explicit numerical scheme has several advantages. First of all, it is mass conserving

which is not given for the implicit scheme. Within ECHAM5, cloud microphysical processes including sedimentation are treated sequentially. Using implicit or more sophisticated explicit schemes would require a total restructuring and subsequent retuning of the model. Furthermore, sensitivity studies regarding the sedimentation of hydrometeors applying different numerical schemes (i.e., explicit, explicit with correction steps [**?**, MPDATA,]]Smolarkiewicz1998 and implicit) yield similar results [Müller(2007)] (if e.g., 3 hourly averages are considered, on the time step scale differences are visible). The implementation of more sophisticated numerical schemes and further comparison with the explicit scheme is work in progress.
It is shown in the paper that the results converge the larger the number of sub-time steps become. It is true that the results depend on the number of sub-time steps as long as only a few sub-time steps are used. This is due to the application of maximum fall speed (=grid velocity) to ensure numerical stability for the explicit scheme.
Numerical efficiency (i.e., relative costs) analysis of the sedimentation scheme depending on the number of sub-time steps is added to the manuscript. A study conducted by [Müller(2007)] showed that one sedimentation integration step with an implicit scheme would require 1.7 times more CPU-time than with the explicit scheme. An first-order approximated implicit scheme would be more efficient (0.88 of the CPU time of the explicit scheme). Most computational intensive would be the use of an explicit scheme with correction steps (e.g., MPData) where the CPU-time increases more than twofold.

- The derivation of the fall velocities for rain water mass and rain drop number concentration is revised and rewritten. The “crude piecewise linear approximation” is a direct result of the integration of the flux equation using the rain drop size distribution and the expression for the fall speed of a single drop. This integral cannot be solved analytically thus asymptotic solutions for $D \rightarrow 0$ and $D \rightarrow \infty$

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are presented. Sensitivity studies revealed that the model results do not depend on whether a gradual transition between the two asymptotic solutions is used or not. Hence, the piecewise linear approximation is used for simplicity.

- The simulations in the revised manuscript encompass different fall speeds for mass and number (i.e., two-moment). The general results and conclusions are not altered by that.
- The microphysical parameterizations are not changed compared to ECHAM5-HAM [Lohmann et al.(2007), and references therein]. Additional parameterizations are mentioned and explained in the paper (sedimentation, break-up).
  At the moment, evaporation of rain leads to a shrinking of the rain drops because rain drop mass is reduced but not rain drop number. Reducing the number of rain drops in a way that the rain drops do not shrink leads to slightly lower RWP but hardly any changes in the precipitation (see below for explanation). Nevertheless, the evaporation parameterization is changed so that N is decreasing proportional to the rain water mass resulting in constant rain drop size as suggested by [Khairoutdinov and Kogan(2000)]

Reply to "Some detailed comments":

p2, l. 34: This statement is correct if the results presented by [Wood(2005)] are considered. In fact it is true that within models rain water first has to be formed by autoconversion which initiates the rain formation. Subsequently most of the precipitation is formed by accretion rather than by autoconversion to be consistent with atmospheric processes (see also [Rogers and Yau(1989), Pruppacher and Klett(1997)]). The overestimation of the importance of the autoconversion is a direct effect of the diagnostic treatment of rain in most climate models where all rain water is removed within one time step and has to be created newly by autoconversion in the next time step. Within the real atmosphere this does not happen as rain is not completely removed. There are

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always rain drops left in the atmosphere which collect cloud drops (accretion) much more efficiently than cloud droplets collect each other (autoconversion). These processes are represented more realistically in the prognostic rain scheme.

p. 2, l. 54: This sentence has been rewritten such that the use of the diagnostic schemes for precipitation is justified by results presented by [Ghan and Easter(1992)].

p. 3, l. 86: The reviewer is right and the introduction of prognostic treatment for snow is work in progress. But as the current study focuses on warm rain processes and the effect of giant CCN (like sea salt, described in another publication) on it, we limited ourself first to rain.

p. 4, l. 105: The sentence has been changed.

p. 5, l. 133: The reviewer is right.
Sensitivity studies were carried out to test how changes in the rain drop number concentration due to evaporation influence the results. Figs. 1 (see `http://www.iac.ethz.ch/people/rposselt/Reply/reply_paper`) shows that a decreasing rain drop number during evaporation leads to a slight decrease in the rain water path and hardly any changes in the precipitation. This results from slightly larger rain drops compared to the simulations with constant N (where the rain drop size decrease) which are removed slightly faster from the atmosphere and thus less are available for microphysical processes. Therefore, less rain water is obtained due to accretion. But the differences are so small that the choice of the evaporation parameterization does not influence the presented results. In the revised version of the paper, the evaporation rate is changed assuming a constant mean rain drop size instead of a constant rain drop number concentration.

p. 5: A parameterization for the self-collection of rain drops is lacking in [Khairoutdinov and Kogan(2000)]. Thus, P_{scr} is parameterized according to [Beheng(1994)]. This is added in the text.

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p. 6, l. 155: The reviewer is right. A sensitivity study done to evaluate the difference between one-moment and two-moment fall velocities is presented in Figs. 2 (see http://www.iac.ethz.ch/people/rposselt/Reply/reply_paper). The gravitational sorting of the rain drops (for two-moment) generally leaves smaller drops in the atmosphere which subsequently have lower fall speeds. Thus in both considered case studies, rain water remains longer in the atmosphere resulting in a larger RWP (and lower TWP due to higher accretion rates) and slightly higher precipitation rates.
In the revised version of the paper the two-moment fall speeds instead of the one-moment ones are used. But in general, the overall results and conclusions remain the same.

p. 6-7: The derivation of the fall velocity for rain water mass and rain drop number concentration was rewritten and shortened (see also preceding item)

p. 7, Eq. (10): We compared the fall speed formulations of [Pruppacher and Klett(1997)], [Böhm(1990)] and [Rogers et al.(1993)] (see Fig. 3, see http://www.iac.ethz.ch/people/rposselt/Reply/reply_paper). The shown differences are sufficiently small and do not necessitate a new derivation of the fall speed for rain drop mass and number.

p. 7, Eq. (11): Eq. (11) is obtained by assuming that for $D \leq 745\,\mu m$ the fall speed of a single drop can be expressed as $v_{s,1} = v_{s,2} + v_{corr}$ (with $v_{s,1}$ being v_s for $D \leq 745\,\mu m$ in Eq. (10) and $v_{s,2}$ being v_s for $D \geq 745\,\mu m$). Assuming an exponential form for $v_{corr} = c_1\,\exp(-c_2\,D)$ one get the following values for the constants $c_1 = b_2 - b_1$ and $c_2 \sim 5\,b_3$. Putting the results together leads to Eq. (11): $v_s = b_1 - b_2\,\exp(-b_3\,D) + (b_2 - b_1)\,\exp(-5\,b_3\,D)$

The fall speed for the (bulk) rain water mass v_m presented in Eq. (12) is obtained by integrating Eq. (3) using Eq. (7) ($f(m)$) and Eq. (11) (v_s) with the help of the moments given in Eq. (9).

Within the paper this part is rewritten to make clearer where Eqs. (11) and (12) come from.

p8, l. 204: This approximation is necessary to ensure numerical stability if an explicit scheme is used. We are aware that implicit schemes would not require this approximation but have other disadvantages. First of all, implicit schemes are not mass conserving. Furthermore, implementing an implicit scheme into the given structure of the ECHAM5 microphysics scheme would require a total restructuring and subsequent retuning of this routine which is beyond the scope of this paper. Besides, sensitivity studies comparing explicit and implicit sedimentation schemes yield similar results [Müller(2007)].

p. 8: ECHAM5 does not contain a parameterization for the collisional break-up and it is beyond the scope of this study to include one. The approach for the spontaneous break-up presented here should only avoid the presence of too large, instable drops.

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