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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Two-moment bulk stratiform cloud microphysics in the GFDL AM3 GCM: description, evaluation, and sensitivity tests" *by* M. Salzmann et al.

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We very much appreciate this insightful and encouraging review.

General comments:

The base model used in the present study is identical to the AM3 model version being described in Donner et al. (manuscript in preparation) except for the changes described in the manuscript. The version described in Donner et al. is currently also being used at GFDL in preparation for IPCC AR5. Our two main changes to this version are the use of 32 instead of 48 vertical levels and that we do not include interactive chemistry. Based on previous sensitivity studies with a 48-level prototype version

including interactive chemistry these changes do not significantly impact the microphysical results discussed in our manuscript (the additional vertical levels are in the stratosphere). Several migrations of the two moment microphysics implementation to updated model versions during the AM3 development phase have also had very little impact on the microphysical properties discussed in the present manuscript. Among other considerations this has influenced our decision to submit the present manuscript prior to finalizing the other two manuscripts.

We did change the citations of the Donner et al. and the Golaz et al. manuscripts from 2010 to "in preparation" as suggested by the referee.

Detailed comments:

1. Section 2 has been re-arranged as suggested.

2. Eq. 2 is inspired by Ghan et al. (1997), although they argue that it is preferable to diagnose σ_w directly from the turbulent kinetic energy (TKE). TKE is, however, not predicted in AM3. Instead of Δz, one could also specify a fixed mixing length (e.g. as in MG08), or a mixing length that varies between the boundary layer and the free troposphere (Wang and Penner, 2009). For either method, it is common to prescribe a lower bound (often $\sigma_{\text{min}} = 0.1$, but higher values are also found in the literature). For $\sigma_{\text{min}} = 0.7$ the lower bound σ_{min} is effective in about 98% of all cases. For the sake of the present study, we retained the formulation that is used in the base model, changing only σ_{min} to 0.3 m s^{-1} for liquid (which is the same value as in Storelvmo et al. (2006)) and to 0.25 m s^{-1} for ice (see reply to Anonymous Referee #2).

3. p. 6382, l. 1: For coastal grid boxes, the coefficient in Eq. 4 is weighted by the land/ocean fraction.

4. p. 6382, l. 4/Table 2: The net radiation flux at the TOA is 0.9 W m^{-2} in the NEW and 1.2 W m^{-2} in the BASE run. (p. 6396, l. 8), which is comparable in magnitude to the widely cited Hanson et al. (2005) estimate based on ocean heat uptake of

0.85±0.15 W m^{-2}. We have included the simulated netradTOA in Table 2 of the revised manuscript.

5. The main tuning in the NEW run is the decrease of the minimum standard deviation of the vertical velocity PDF used for calculating droplet activation from 0.7 m s^{-1} in the BASE run to 0.3 m s^{-1} in the NEW run. This increases the top of the atmosphere net radiation flux (netradTOA) by more than 2 W m^{-1}. A corresponding statement has been added to the revised manuscript (Sect. 2.2.1):

"Here, sub-grid variability of w is parameterized using Eqs. (1) and (2), but the minimum standard deviation of the vertical velocity PDF in Eq. (2) is decreased from 0.7 in the BASE to 0.3 m s^{-1} in the NEW run, thereby increasing the top of the atmosphere net radiation flux (netradTOA) by more than 2 W m^{-1}."

A similar sensitivity to decreasing σ_{min} is also found for the standard AM3 stratiform cloud scheme (Golaz et al., manuscript in preparation).

6. The following sentence has been added to the description of the MG08 scheme (Sect. 2.2.1 of the revised manuscript): “A lower droplet number concentration limiter is not applied.”

7. p. 6384, l. 4–9: The following sentence as been added to the revised manuscript: “The maximum mean diameter for cloud ice (400 μm) and the minimum (2 μm) and maximum (50 μm) mean diameter for cloud droplets are as in MG08.”

8. Phoretic processes (e.g. Baker, 1991) are not taken into account.

9. Between -35 and -40, the Liu et al. (2007) parameterization is applied, but liquid hydrometeors are still allowed to exist, e.g. in the case of insufficient ice nuclei.

10. p. 6384, l. 10, p. 6390, l. 11: The Bigg et al. parameterization is applied to existing droplets, while the modified Meyers et al. formula is used to describe "immersion nucleation" as in MG08. An alternative that could potentially allow a more consistent treatment in the future might be to calculate droplet activation throughout the tropo-

sphere (i.e. also below the homogeneous freezing threshold temperature) and to then freeze the newly formed droplets within the same time step.

11. p. 6384, l. 21: A similar point has been mentioned in Sect. 2.4 (p. 6389, lines 18–20, Sect. 2.2.3 of the revised manuscript). It has been clarified as follows (in Sect. 2.2.3):

“At present, immersion nucleation is treated independently of droplet activation which is only calculated above the threshold temperature for homogeneous ice nucleation. Alternatively, droplet activation could in principle be calculated even at very low temperatures and could then be used to limit the number of newly formed ice particles due to immersion nucleation. “

12. p. 6385, l. 9: 0.3 m s^{-1} is closer to the values used in other studies and it also shifts the radiation balance toward that in the BASE run. The lower limits are hit frequently, in spite of the fact that K_T includes a contribution from cloud top radiative cooling. Sensitivity studies with the new cloud scheme and $\sigma_{min} = 0.7$ m s^{-1} show that the adjustment does not determine the difference in droplet numbers between the BASE and the NEW run (not shown in the manuscript). In particular, the finding of higher droplet number in the BASE run due to more super-cooled droplets is not affected.

13. p. 6388, l. 17: We removed the second reference to the Kärcher et al. (2007) paper from Sect. 4.2 and omitted the "see review of laboratory data by" from the last reference to Kärcher et al. (2007) in Sect. 5. We also removed the repetitive statement "At present, scavenging is treated independently from aerosol activation." from Sect. 3.7.

14. p. 6390, l. 19: The 20 μg m^{-3} is an ad-hoc choice based on "typical values". It is for example within the range of average soil dust concentrations (0.25±0.16 μg m^{-3}) measured during the Mount Werner project by the Interagency Program for Visual Environments (IMPROVE) (DeMott et al., 2003). In the future, it would be desirable to include the parameterization by Phillips et al., 2008.

15. p. 6407, l. 7: The reference to Lohmann et al., 2010 has been added.

16. p. 6429, Table 1: For ice nucleation, "modified Meyers formula" has been added to the "NEW based on:" column and the contents of the fourth footnote has been moved to the table.

17. The model version used in Quaas et al. (2009) is a prototype version which includes essentially the same features as the version used in the present study. Since the version used in Quaas et al. no major new components have been incorporated into the model, but there have been several bug fixes and the model has been re-tuned for radiation balance.

18. p. 6433, Fig. 2: In the revised manuscript, we explain the dashed lines in (b) in the caption and included a red line in the legend.

19. p. 6433, 6434, Figs 2 and 3: In the revised manuscript, we added red dashed lines in the legends of Figs 2a,b,c,d,e and in Fig. 3a.

References not in the manuscript:

Baker, B. A.: On the role of phoresis in cloud ice initiation. J. Atmos. Sci.,48, 1545–1548, 1991.

Phillips, V. T. J., DeMott, P. J., and Andronache, C.: An empirical parameterization of heterogeneous ice nucleation for multiple chemical species of aerosol. J. Atmos. Sci., 65, 2757–2783, 2008.

DeMott, P. J., Cziczo, D. J., Prenni, A. J., Murphy, D. M., Kreidenweis, S. M., Thomson, D. S., Borys, R., and Rogers, D.C.: Measurements of the concentration and composition of nuclei for cirrus formation. Proc. Nat. Acad. Sci., 100, 14655–14660.

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