Development of the two-moment cloud microphysics for liquid and ice within the NASA Goddard earth observing system model (GEOS-5)

Barahona et al.

1 General Comments:

Overall the paper gives an extensive overview of the state-of-the art microphysical parameterizations and their application in the GEOS-5 model. The authors developed a two-moment cloud microphysics scheme which accounts for a variety of physical processes. The new scheme was tested thoroughly in climate runs for a period of 10 years and with sensitivity studies for a period of two years. For the model evaluation a great range of satellite products were used. Therefore, I recommend to accept the paper for publication after revisions.

2 Specific Comments:

The content of the paper is very extensive. A clear and consistent notation would simplify the complex issues stated. Especially the abbreviations used at the beginnings of new sections should be written out. All the plots are missing labels at the legends. In the following, comments for individual sections are stated:

Section 2.3 Please give a short summary and overview of the different subsections to follow. Also, it would be helpful to mention at the beginning, that the modifications to the MG08 scheme are listed. Overall this section could profit from a bit more physical background in addition to the equations from parameterizations. Also it is hard to distinguish between already existing parameterizations and new developments. Please clarify this.

Section 2.3.2 The homogeneous nucleation (Koop et al. 2000) is only mentioned in one sentence and even though it is said to be dominant (Sec. 3.5). At the beginning of the explanation for heterogeneous nucleation ($T < 235K$) please motivate the additional implementations to Ph13, i.e., accounting for the competition between the nucleation modes and preexisting ice crystals.

Section 2.3.5 Where is the vertical velocity accounting for preexisting ice crystal included into the ice nucleation scheme? Please clarify the relation between $N_{i,pre}$ (preexisting ice crystal concentration) and $N_{c,nuc}$ from Eq. (16) (nucleated ice crystal concentration). Also, the accounting for preexisting ice crystals by reducing the vertical velocity was also applied in the ice nucleation parameterization by Krcher et al. 2006. Maybe this should be mentioned.

Section 2.4.3 Please note the existence of graupel in the convection scheme earlier. It is also noteworthy that ice and snow are treated as a single species. This was not clear, as previously only cloud ice, liquid, rain and snow where mentioned.

Section 3 In this section there are a lot of abbreviations, a Table would be helpful. Also an overview of the characteristics for the different data sets would be useful.

Section 3.1 The explanation for Figure 1 describes that the underestimation of the CLDMD in the high latitudes of SH and NH is also smaller in NEW than in CTL. Yet it looks like only the underestimation is reduced in the NH with NEW. Please mention the overestimation in CLDMD with NEW in SH. Also the CLDHI is not only overestimated in the marine high

latitudes, it generally increases the overestimation already present in CTL. What might be a possible source for this overprediction?

Section 3.2 Please explain the two mechanisms on a more physical basis. How does the restriction of ice nucleation to supersaturated regions lead to ice supersaturation? S_{crit} is the critical saturation ratio and is therefore not larger than 1 and dimensionless. In this section S_{crit} is rather used as the critical relative humidity, analogue for the clear sky saturation ratio.
Figure 2: Please be more accurate about what data is used. In the plot caption it states, that it is annual data. Which year? Does Fig. 2 include cloudy and clear sky saturation? Are values only above $S_{crit} > 100\%$ considered, as there are hardly any values around saturation at $S_{crit} = 100\%$. Also I would expect a smoother profile for an annual global frequency distribution. What is the source for the outliers? Please discuss the reason for the high critical saturation ratios, especially the peak of S_{crit} at 150% in the left plot. According to this plot the homogeneous nucleation regime (S_{crit} 140%) is very dominant.
Figure 3: What time interval is investigated? Are the MOZAIC and AIRS data only for clear sky as well? Are the high clear sky saturation ratio values above 160% and the outlier at 190% physical? The blue and red shades of the left plot turned purple and pink in my print. Legend labels are missing for the middle and right plot. What might be a reason for the maximum supersaturation at 700 hPa and $60S$ in the GEOS-5 Output (middle plot)? Please discuss possible reasons for the vast differences of S_{crit} (Fig. 2 left) and clear sky $S_{i,c}$ (Fig. 3 left).

Section 3.4 Please be more critical in discussing Fig. 5. Also, in Fig. 5 the middle plot using the ARGACT CCN parameterization is not mentioned in the text.

Section 3.5 What would be a possible explanation for the wave-like pattern in Fig. 6d? Please introduce the three plots in Fig. 7 and specify in the text, which one is referred to when discussed. The 30% contribution of heterogeneous nucleation can not be seen clearly in South America.

Section 3.6 What is the regarded time range for all figures in this section? Why is there such a big reduction in total ice condensate in the tropics with GEOS-5 NEW in Fig. 8?

Section 3.7 Please discuss the different frequency peaks at different temperatures in Fig. 11 for NEW. Are these the different nucleation modes?

Section 3.8 As stated earlier, please explain what the COSP package is. Is MODIS data already used in this package?

Section 5 In line 15: The critical supersaturation in Eq. (15) only indirectly accounts for subgrid scale dynamics and aerosol properties.

3 Technical Corrections:

- p. 5291, line 16: supersaturation needs to be ice supersaturation
- p. 5293, line 19: insert comma after At high resolution
- p. 5294, line 12: clarify rain and snow variables
- p. 5295, line 16: I find the notation confusing of the two moments: q_l,q_i, n_d and n_c, why not q_l,q_i, n_l and n_i?

- p. 5296, line 12: define D
- p. 5296, line 18: cloud ice number mixing ratio n_i inconsistent to earlier notation
- p. 5297, line 3: clarify autoconversion (cloud droplets?)
- p. 5298, line 4: end of sentence, . after Eq . (4)
- p. 5298, line 14: wrong section referenced, should be 2.3.3
- p. 5298, line 5-16: please be a bit a more precise about the the mathematical derivation of the Eqs. (10) and (11). How does q_{mx} from Eq. (8) relate to q_{mx} from Eq. (10)? How does q_t appear in Eq. (11) as q_{mx} was eliminated?
- p. 5300, line 2: hereafter is missing before FN05
- p. 5300, line 2: wrong words FN05 is an, rather FN05 give an analytical solution
- p. 5300, line 22: hereafter is missing for BN09
- p. 5300, line 23: Expression: BN09 is derived, In BN09 is derived
- p. 5301, line 6: Confusing to use μ for the moments, as μ was already used for the gamma distribution (Eq. 2)
- p. 5301, line 10: hereafter is missing for Ph13
- p. 5302, line 10: What is S_{hom}? Did you use a numerical fit based on Koop et al. 2000 as done by, e.g., Krcher and Lohmann 2002, Ren and MacKenzie 2005?
- p. 5302, line 20: are the equations (Eq.(17)-(19)) for the mixed-phase regime all based on Ph13? If so please mention.
- p. 5303, line 4: for w_{sub} reference subsection 2.3.4
- p. 5303, line 17: notation T -3 K
- p. 5304, line 18: in situ cirrus ?
- p. 5305, line 2: double citation: MG08 and Morrison and Gettelman, 2008
- p. 5305, line 6: what value is assumed for λ_m (l_m in the free troposphere)?
- p. 5305, line 17: introduce comma Using this, a
- p. 5306, line 14: end of sentence, . behind Eq. (26)
- p. 5306, line 22: $S_{l,max}$ was not introduced
- p. 5307, line 10: alpha and beta are not included in Appendix Table A1
- p. 5307, line 12: In Eq. (27), what is $\lambda_{i,pre}$ (also not mentioned in Appendix B)? $N_{i,pre}$, $w_{sub,pre}$ and λ_i,pre are not included in Appendix Table A1
- p. 5307, line 12: supersaturation needs to be ice supersaturation
- p. 5309, line 3: The initial condition IN Eq. (29)-¿The initial condition FOR Eq. (29)?
- p. 5310, line 4: for Eq. (32), please introduce n_i, λ_i, $S_{i,wsat}$ (n_i, λ_i not in Table A1; $S_{i,wsat}$ is differently in Table A1)

- p. 5311, line 13: end of sentence, . behind Eq. (34)
- p. 5312, line 8: redundant word approximated calculated
- p. 5312, line 10: what is λ_g
- p. 5312, line 14: end of sentence, .
- p. 5312, line 16: end of sentence, . behind Eq. (39)
- p. 5312, line 18: end of sentence, . behind Eq. (40)
- p. 5312, line 19: expression: are used into Eq.(30)
- p. 5312, line 19: is the graupel equation not used for Eqs. (28) and (29)?
- p. 5313, line 26: add total cloud fraction to f_c abbreviation
- p. 5314, line 11: write out NH in full, or introduce abbreviation
- p. 5314, line 14: write out SH in full, or introduce abbreviation
- p. 5314, line 26: Eq. (7) is for q_c not for q_i
- p. 5315, line 19: 'that for the conditions of Fig. 3', what are the conditions? Is this only upper troposphere?
- p. 5316, line 8: please write out 'w_{sub}' at beginning of section
- p. 5317, line 14: write out N_d (preexisting in-cloud number concentration)
- p. 5317, line 15: what is COSP output?
- p. 5317, line 16: missing explanation for $R_{eff,liq}$
- p. 5317, line 24: note that GEOS-5 NEW is depicted in Fig. 5
- p. 5318, line 20: wrong section referenced
- p. 5318, line 26: 'freeezing'
- p. 5318, line 27: why integrate over the cooling rate?
- p. 5319, line 17: $N_{c,cv}$ is denoted as N_{cnv} in Fig. 6d
- p. 5320, line 25: replace '+' by 'and'
- p. 5321, line 18: stated in line 13 is that LWP is not generated by COSP, how come the annual average of GEOS-5 COSP is used here? In the plots the LWP mean of GESO-5 is $37.1\,g\,m^{-2}$, in the text it states $60g\,m^{-2}$.
- p. 5321, line 26: the IWC from GEOS-5 is lower
- p. 5321, line 28: what is ISCCP?
- p. 5322, line 4: replace '+' by 'and'
- p. 5324, line 24: word missing 'the MODIS COSP simulator'. Is the annual mean for CTL or NEW?
- p. 5327, line 10: 'velue' should be value

- p. 5329, line 22: 'the' twice
- p. 5330, line 21: 'have' is missing in sentence
- p. 5352, Table 1: what is N_a? Not included in Appendix Table A1 for List of symbols either.
- p. 5358, Figure 1: The annual mean difference in high level clouds (CLDHI) for the NEW run has a wrong title (CLDMD NEW-ISCCP)
- p. 5359, Figure 2: Which year is this? For the zonal mean the label for x legend is missing. In caption: Solid lines (right) represent the annual mean tropopause pressure. I think you mean the bold solid line, while the solid lines are contour lines.
- p. 5361, Figure 4: Please enlarge figure and write out σ_w