Review for Geoscientific Model Development (GMD)
5 July 2022

Title: Impacts of Ice-Particle Size Distribution Shape Parameter on Climate Simulations with the Community Atmosphere Model Version 6 (CAM6)
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MS No.: gmd-2022-95
MS type: Model evaluation paper

General Comments:

Global Climate Models (GCMs) simulate ice clouds using "two-moment schemes" having prognostic solutions for ice particle number concentration (N_i) and cloud ice water content (IWC). The ice particle size distribution (PSD) is generally parameterized as a gamma PSD as described in Eq. 1 in this manuscript, consisting of three variables: N_0, λ and μ. Knowing N_i and IWC, N_0 and λ are solved for, but in order to obtain mathematical closure for the PSD, μ is given an arbitrary constant value. To my knowledge, there are very few papers investigating the impact of μ on ice cloud microphysical processes in climate models, and this paper appears to be the most thorough and appropriate for GCMs to date. The paper is well organized and well written, providing important new findings relevant to a GMD readership.

In the study by Mitchell et al. (2006, Atmos. Res.), a snow growth model was developed and tested against aircraft PSD probe measurements where the aircraft descends from cloud top to cloud base under quasi-steady state widespread snowfall conditions, where PSDs were modeled as gamma PSDs. Optimal agreement between the height-evolution of measured and predicted PSDs was obtained for a μ value of -0.6. Assuming the snow growth model was developed properly, this suggests that the PSDs sampled on this flight were characterized by slightly negative μ. Other studies (e.g., Herzegh and Hobbs, 1985, QJRMS; Gordon and Marwitz, 1986, JAS; Mitchell, 1988, JAS) suggest μ typically ranges between 1 and -1 in ice clouds, while Heymsfield (2003, JAS, Part 2) finds μ lies mostly between -2 and 2 when natural ice PSDs are parameterized as gamma PSDs. Thus, the μ values of 2 and 5 assumed for ice clouds in this study appear atypical, but the impacts of changing μ from 0 to 2 (shown in this study) are relevant to real cloud microphysical and radiative processes. This paper would be much more realistic and useful if it also evaluated the impact of changing μ from 0 to -1. Negative values of μ are common when ice crystal nucleation rates are relatively high (Herzegh and Hobbs, 1985, QJRMS).

Mitchell (1991, JAS) found that for negative μ values (i.e., superexponential PSD), aggregation was the only growth process that substantially increased ice particle sizes, whereas for positive μ, both aggregation and vapor diffusion contributed to ice particle size increases. This is an example of how ice particle growth processes act differently depending on the sign of μ and illustrates the need to consider both positive and negative μ values.

Major Comments:

1. Line 68: Sentence states that μ_i is not considered in the default MG scheme because $\mu_i = 0$. While it is true that $\mu_i = 0$, stating that it was not considered is misleading. On a number of occasions, Hugh Morrison indicated to me that he was seeking more information about μ_i and was exploring new ways of treating it (prior to the release of CAM5). After consulting with his peers, he decided a value of zero was most reasonable if a fixed value was to be used.

2. Table 1: In the MG scheme, the air density prefactor for the mass-weighted ice fall speed is raised to the power of 0.54 (following Heymsfield and Bansemer 2007), not 0.35 as shown in Table 1. The simulations may need to be rerun if this incorrect value of 0.35 was used.

3. Line 317: There are references to support this statement; please add some.

4. Lines 381-383: This finding appears similar to that reported in Mitchell (1991, JAS) titled "Evolution of snow size spectra in cyclonic storms. Part II: Deviations from the exponential form", where it was found that the IC vapor deposition process was accelerated by increasing μ_i.

Technical Comments:

1. Line 47: Common Atmosphere Model => Community Atmosphere Model?
2. Line 89: PDF => PSD?
3. Caption for Fig. 2 near bottom: "The two black lines" => "The two black dashed curves"?
4. Lines 279-280: Are the superscripts for *Mu and Mu correct?