# Responses to 2nd Referee's Comments

***General comments***

*In this study the modal aerosol modules (MAM) are incorporated into a general circulation model, Community Atmosphere Model version 5 (CAM5). The CAM5 with MAM can calculate global aerosol distributions simulating aerosol size distributions considering the mixing state (internal or external), and then this work is also effective for simulating cloud droplet nucleation explicitly. On the whole, this study and manuscript is good, therefore I suggest that this manuscript will be able to be published if the authors fully address specific comments indicted below. However, the authors should consider that it is separated into two papers because it is too long although I can understand it is a description paper and this journal for model developments.*

→Reply: We thank the reviewer for your encouraging comments.

We agree with the reviewer that the whole paper is too long, although it is a model development paper. Since the description and evaluation of the modal aerosol module (MAM) are two integrated parts, and much of the comparison between MAM3 and MAM7 is in the evaluation section, we did not split the paper into two shorter ones (e.g., one for description and one for evaluation of MAM, or one for MAM7 and one for MAM3). Instead we moved a large part of the paper to the supplementary. We moved most of the model description to the supplementary including: Sections 2.1.1 to 2.1.10 (Aerosol processes), Sections 2.2 (Clouds), 2.3 (Radiation), 2.4 (Turbulence) and 2.5 (Resolved transport). We left the paragraphs that introduce MAM3 and MAM7 in Section 2.1 in the main text. Readers can easily look at the supplementary for the details of aerosol and other physical processes. We note the original GMDD version has 16 pages of references, with many cited in the model description, and these were moved to the supplementary as well. All together we moved about 25-30 pages of text, references and Tables associated with the model description to the supplementary.

In addition we moved Section 4.4 (Evaluation of Cloud property) to the supplementary. We removed Figure 27 in Section 5 by just describing it, as its results are not remarkably different from Figure 13. Through the above changes, we estimate the paper will have about 70-75 pages in GMDD format, compared to the original

paper's 114 pages, which is a manageable page number for readers, considering that this is a model description paper.

**Specific comments**

*Title: It is too general, so that this title should be changed more specifically, from which readers can understand what do the authors do in this study.*

→Reply: Following the reviewer comment, we changed the title to "Toward a minimal representation of aerosols in climate models: Description and evaluation in the Community Atmosphere Model CAM5". The goal of this paper is to provide a description and evaluation of the aerosol module with two representations of aerosols in CAM5 (one comprehensive version and one much simplified version). A companion paper (Ghan et al., Toward a minimal representation of aerosols in climate models: Comparative decomposition of aerosol direct, semi-direct and indirect radiative forcing, submitted to J. Climate, 2011) presents details of direct and indirect aerosol effects. We also modified the end of introduction section to make it clearer of the goal of this study: "The goal of this paper is to provide a description and evaluation of the aerosol module and its two representations".

*P3847, L9-14: "Major approximations in MAM3 include assuming immediate mixing of primary organic matter (POM) and black carbon (BC) with other aerosol components, merging of the MAM7 fine dust and fine sea salt modes into the accumulation mode, merging of the MAM7 coarse dust and coarse sea salt modes into the single coarse mode, and neglecting the explicit treatment of ammonia and ammonium cycles." It is difficult to understand such an unkind sentences. I think that you do not need it in the Abstract. Instead of it, you should state a primary aim of this manuscript.*

Following the reviewer comment, we removed these sentences, and added the primary aim of this manuscript in the revision: "This paper provides a description and evaluation of the aerosol module and its two representations. Sensitivity of the aerosol lifecycle to simplifications in the representation of aerosol is discussed".

*P3847, L18-20: "because of the assumed hygroscopic nature of POM, so that much of the freshly emitted POM and BC is wet-removed before mixing internally with soluble aerosol species". It cannot be understood why this is a reason for a small differences in POM and BC between MAM3 and MAM7. You have to rewrite if you think it is important.*

In MAM3, POM and BC are emitted into the accumulation mode, and thus are instantaneously mixed with soluble species (e.g., sulfate) and can immediately experience in-cloud scavenging. (The below-cloud scavenging is inefficient for particles of their size.) In MAM7, POM and BC are emitted into the primary carbon mode and then aged into the accumulation mode (mixed with soluble species). When we assume that freshly emitted POM is hygroscopic, the MAM7 POM and BC in the primary carbon mode can experience in-cloud scavenging before they are aged into the accumulation mode. Thus the difference in POM between MAM3 and MAM7 is small. Following the reviewer comment, we removed this sentence when we shortened the abstract.

*P3488, L16: Absorbing aerosols necessarily do not reduce the cloud cover. If they concentrate just above the surface or in the boundary layer, they can increase cloud cover due to getting instability of the atmosphere through the semi-direct effect (e.g., Koch et al. 2010, Takemura et al. 2011).*

Following the reviewer comment, we changed the word "reduce" to "change" in the revision.

*P3494, L1: IPCC AR5 is firstly appeared. Write full name.*

Done.

*P3494, L8-9, L12-13: "sulfur from forest fire and grass fire is emitted at higher elevations (0–6 km)", "POM and BC from forest fire and grass fire are emitted at 0–6 km". How are the sulfur, POM, and BC emitted? Constant mass mixing ratio to the vertical profile? And what is a reference of this height?*

The text was changed to: "Injection height profiles for forest fire and grass fire emissions are derived from the corresponding AeroCom profiles (Dentener et al., 2006), which give emissions in 6 altitude ranges (0-0.1, 0.1-0.5, 0.5-1, 1-2, 2-3, and 3-6 km). Emission rates (kg $m^{-3}$ $s^{-1}$) are assumed uniform within each altitude range." Dentener et al. (2006) referred "D. Lavoue (2003), personal communication" for the injection heights.

*P3498, L19: What is the accommodation coefficient?*

It is the probability of sticking when a gas molecular encounters the surface of an aerosol particle. The sentence was changed in the revision to make it clearer.

*P3499, L4: What is $M_{SO4,cond}$?*

It is the mass of sulfate condensing on the aerosol particles in the primary carbon mode during a model time step (30 mins). We made this clear in the revision.

*P3500, L17: Explain the UW parameterization.*

UW parameterization means "University of Washington parameterization". We changed "UW parameterization" to "Park and Bretherton (2009) shallow convection parameterization" in the revision.

*P3501, L8: Write a reference for assuming a cloud regeneration time scale of one hour. And describe a sensitivity of the time scale if possible.*

A reference (Lelieveld, J., and P. J. Crutzen, 1990, Influences of cloud photochemical processes on tropospheric ozone. *Nature*, **343**, 227-233) was added in the revision, and "regeneration time scale" was changed to "in-cloud residence time for air parcels" for consistency with previous work. The one-hour value is incorrect; actually three hours is used in the model. We are sorry for the typo, which was corrected in the revision. Sensitivity tests with different time scales will be performed and analyzed in the future study. We added a note in the revision.

*P3502, L10-11: "The activation fractions currently are 0.0 for the primary carbon mode, 0.4 for the fine and coarse dust modes, and 0.8 for other modes". Do you have any references for these values? I guess they are one of the tuning factor.*

Yes, the activation fraction is basically a tuning factor, with lower values reflecting the lower hygroscopicity. We are developing a more detailed treatment of activation in convective clouds.

*P3502, L21-22: Simply describe the method of calculation of the scavenging coefficient for interstitial aerosols (which parameters are depended on, and, if possible, with a equation).*

Following the reviewer comment, we added more description of calculation of the scavenging coefficient for interstitial aerosols and a reference (Wang et al., 2011, Uncertainty assessment of current size-resolved parameterizations for below-cloud particle scavenging by rain. *Atmos. Chem. Phys.*, **10**, 5685-5705. doi:10.5194/acp-10-5685-2010 and its Equation 2) to a recent in-depth study of below-cloud scavenging

in the revision.

*P3504, L20-21: "The treatments of droplet and crystal nucleation have been modified." What has been modified from?*

Here we meant that the treatments of droplet and crystal nucleation in Morrison and Gettelman (2008), which was based on CAM3.6, have been modified in CAM5. We modified the sentences in the revision to be clearer. Now it reads "The treatment of droplet nucleation in MG08 has been modified in CAM5 to be consistent with aerosol activation as described above. The treatment of ice nucleation in MG08 has also been modified following Liu et al. (2007), ..."

*P3507, L28-29: Explain the lambda and gamma parameters with the shape parameter.*

$\lambda$ is the slope parameter and $\mu$ is the shape parameter of the gamma size distribution for cloud droplets and ice particles. In the original sentence, "gamma parameter" should have been "mu parameter". We added the explanation and made the changes in the revision.

*P3517, L4: "smaller SO2 sources". From Table 6, SO2 source in this study is not small compared with the AeroCom study.*

Following the reviewer comment, to avoid confusion, we removed this sentence in the revision: "This smaller production in CAM5 may be due to smaller $SO_2$ sources … to form sulfate".

*P3533, L20-27: The authors should't write about ammonia/ammonium in the conclusion section because there are not any discussions on them before the conclusion.*

No, there is discussion of ammonia/ammonium before the conclusion section. The life cycles of ammonia/ammonium are explicitly treated in MAM7, and we discuss these in section 3.2 and give their budgets in Table 8. In this paper, we do not present any evaluation of them due to the page limit.

**Technical corrections**

*P3490, L1; P3491, L4: Change "between" to "among".*

Done.