RESPONSE TO ANONYMOUS REVIEW 1

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We thank the anonymous reviewer for his/her thoughtful comments. Our responses to the major points are below. The points correspond, in order, to those in the review.

(1) Points (1), (2), and (3) are discussed together, below:
In regard to the choice of using a 3-D dynamical core or a 2-D dynamical core, please refer to our response to the first point made by anonymous reviewer #2.

The reviewer brings up a worthwhile and valid point regarding the collection of small aerosol particles. Specifically, collisions between droplets (or even large CCN) and small aerosol particles (i.e., radius $<2\mu$m) are very rare due to gravitational settling alone. For particles in this size range, the collection is more influenced by Brownian diffusion to the droplets and large CCN (the temperature and density gradients within the cloud are not significant enough for thermophoresis or diffusiophoresis to be a significant mechanism for the loss of small aerosols). Moreover, simulations performed with Brownian diffusion included in the 2-D continuous bin scheme (not shown) resulted in a negligible effect on the various cloud properties. It is important to note that Brownian diffusion, thermophoresis, and diffusiophoresis are not included in most 1-D bin or bulk models either. Including such processes in the spectral scheme would warrant their inclusion in the other schemes as well. We have commented on this in the revised manuscript.

Moreover, in regard to the inter-model comparison, it is important to keep in mind that the 2-D bin scheme accounts explicitly not only for aerosol regeneration, but also for aerosol effects on condensation/evaporation, which is important for small droplets for which the relative mass of solute to water is higher. Thus, the new model, which is capable of treating regeneration in a consistent and physically accurate manner, includes processes that can only be included in bulk or even 1-D bin schemes with a parameterization. Thus, the opposite sign of the pollution effect on LWP between the 2-D and 1-D bin schemes is a result of the inclusion of

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a more accurate physical representation of the cloud microphysical processes as a whole.

Unfortunately, testing different regeneration schemes with the 2-D bin scheme is unrealistic. The model accounts for the growth of aerosols via collision-coalescence and thus moves the mode of the aerosol size distribution toward larger sizes in a physically accurate and consistent manner. The regeneration schemes used in 1-D models rely on the complete evaporation of cloud droplets in order to predict the number (and potentially size) of the regenerated particles. In the 2-D bin scheme, aerosol particles and droplets are indistinguishable except for the fact that we track the mass of both solute and water in each bin. Unless the ambient saturation ratio falls below the efflorescence point for the given aerosol, the particles will remain "wet" and so complete evaporation does not occur. Moving these particles to another aerosol bin would not conserve the mass of aerosol in the model and is unphysical. Lastly, testing of various regeneration assumptions with 1-D models was performed by *Xue et al.* (2010). The purpose of the current study is to demonstrate the capabilities of the new continuous scheme at capturing the evolution of the aerosol spectrum due to cloud microphysical processing and not to analyze various regeneration assumptions.

Minor Points:

(1) For the purpose of simulating non-drizzling marine stratocumulus, the upper limit of the drop size spectrum used in the study is adequate. The number concentration in the 36th bin remains quite low, i.e., $< 1{\times}10^{-10}$ cm^{-3}. With that said, in other idealized cases, i.e., shallow convection, precipitating, stratocumulus, etc., the upper limit to the drop size distribution will need to be elevated. To show the adequacy of restricting the largest droplet size to 205 μm, we have added a figure showing the evolution of the droplet spectra to the revised manuscript.

(2) The reason for the change in bin 14 but not 15 lies in one of the assumptions used in the model. The last bin in the aerosol size distribution is not permitted to change in order to limit the loss of mass out of the upper boundary due to particles growing beyond the upper size limit. Understandably, this assumption may affect the results, however, given that the aerosols in bins 14 and 15 are similar in

regard to their critical supersaturation and effects on droplet growth, the actual location of aerosols at the high end of the aerosol size spectrum used in the study is insignificant to the overall results. Moreover, limiting the aerosol size spectrum to a maximum size of 1.6 μm is sufficient since the activation characteristics for particles in the micron size range are quite similar. Sensitivity simulations using 20 bins to represent the aerosol size spectrum show a negligible change in the presented results (upper limit is 5.08 μm).

(3) The background aerosol is assumed to be ammonium sulfate. This detail has been added to the manuscript.

(4) Please refer to our response to comment (2) above.

(5) We have changed the manuscript to now read "comprise a set of

$$N_{equ} = \frac{M}{2}(M+1) + M(N-M) + 3 \tag{1}$$

ordinary differential equations (where N_{equ} is the number of equations)."

(6) *Xue et al.* (2010) has been removed from the list of modeling studies of marine stratocumulus.

(7) The surface fluxes are computed using the Monin-Obukhov scheme. We have added the following line to the description of the model setup: "Surface latent heating and fluxes are computed following the Monin-Obukhov scheme."

(8) The sentence should have read "For grid points in which the saturation ratio (S) is greater that 0.95, we assume that the relative humidity (RH) is 95 % for the purpose of initializing the model." This change has been made in the revised manuscript. Thus, when the RH is above 95%, we use 95% as the RH to compute the wet size. Sensitivity tests with different values of this threshold RH show that there is a negligible effect on the results.

(9) We have added the following statement to clarify the use of the terms "overpredict" and "underpredict" in Section 4.1: "Hereinafter, it should be noted that all comparative statements refer to results relative to those from the 2-D continuous bin scheme, unless otherwise noted."

(10) We added the simulation name to the statement so that it now reads: "These effects combine to produce an unrealistic profile of the domain-averaged total condensed water (q_t) profile for the LES_Bulk_NoReg cases"

(11) We have revised the manuscript such that the references to previous modeling studies in which it was shown that an increase in aerosol loading corresponds to an increase in LWP to "(e.g. *Albrecht*, 1989; *Ackerman et al.*, 2003; *Wood et al.*, 2009)"

(12) As mentioned above, we have included figures of the droplet size distributions from the simulations performed with the 2-D bin and 1-D bin microphysics models. Moreover, we have added the following text to the revised manuscript in support of the new figure: "The enhancement in radar reflectivity is corroborated in Fig. 9 in which we show droplet distributions for the 2-D continuous bin model and the 1-D microphysics scheme with and without regeneration. Figure 9 clearly shows the reduction in the number concentration due to suppressed collision coalescence in the "Polluted" case compared with the "Clean" scenario. Furthermore, we see from the 1-D bin microphysics results, the effect of the regeneration assumption on the droplet size distribution. Specifically, at 150 min, in the "Polluted" (dashed) scenario, Fig 9 shows that the 1-D bin model with regeneration produces many more smaller particles compared to the 2-D continuous bin scheme. The potential for the model to overpredict the number concentration was alluded to above and, demonstrated here, results in a large suppression in the formation of drizzle drops relative to the 2-D continuous scheme. Moreover, in the absence of a regeneration parameterization in the 1-D bin model, the mode of the droplet size spectrum is higher in comparison to the 2-D continuous bin scheme. This is a direct result of the fact that without a regeneration scheme, the droplet number concentration is likely to be underpredicted, hence producing larger droplets (assuming the liquid water content does not change much). Figure 9 alone demonstrates the large differences between the bin microphysical modeling approaches."

(13) We have changed the manuscript to now read: "To answer the second question, one can speculate that within a thicker stratiform cloud (i.e. the volume to surface area ratio of the cloud as a whole is larger), the relative importance of regeneration decreases since it is less likely that a parcel of air will interact with drier, entrained air. Conversely, in a thinner stratiform cloud, regeneration will likely be even more important than shown for the illustrated scenario. However, in the cases of cumulus and deep convective clouds, the turbulent nature of these clouds presents an environment conducive to entertainment and complete evaporation of

droplets, even though the cloud itself is rather thick. Understanding the effects of regeneration on these clouds using the model presented here is a subject for future investigation."

Technical Comments

(1) The statement has been revised to now read: "...since after the activated aerosol particle grows within the cloud droplet spectrum,..."
(2) The phrase was changed to "left to right, red, solid".
(3) We removed the word "the" and the phrase now reads "since the critical supersaturation for these particles is smaller".
(4) As per ACP guidelines, we are asked to used "Section" if the word is at the beginning of a sentence and "Sect." if it is in the middle of a sentence. We have followed this rule throughout the manuscript.
(5) We added ρ_w to Eq. (10).
(6) The word "while" was removed so that the phrase is now "... cases; Z increases at...."
(7) "Yellow" has been changed to "red" in the revised manuscript.
(8) We have revised the phrase and it now reads " To answer the second question, one can..."
(9) The citation for *Xue et al.* (2010) was changed to Xue, L.
(10) The units for the x-axis were changed to minutes.

References

Ackerman, A. S., O. B. Toon, D. E. Stevens, and J. A. Coackley Jr. (2003), Enhancement of cloud cover and suppression of nocturnal drizzle in stratocumulus polluted by haze, *Geophys. Res. Let.*, *30*(7), doi:10.1029/2002GL016634.

Albrecht, B. (1989), Aerosols, cloud microphysics, and fractional cloudiness, *Science*, *245*(4923), 1227–1230, doi:10.1126/science.245.4923.1227.

Wood, R., T. L. Kubar, and D. L. Hartmann (2009), Understanding the importance of microphysics and macrophysics for warm rain in marine low clouds. Part II: Heuristic models of rain formation, *J. Atmos. Sci.*, *66*, 2973–2990.

Xue, L., A. Teller, R. Rasmussen, I. Geresdi, and Z. Pan (2010), Effects of aerosol solubility and regeneration on warm-phase orographic clouds and precipitation simulated by a detailed bin microphysics scheme, *J. Atmos. Sci.*, *67*, 3336–3354.