We greatly appreciate the time and effort taken by both reviewers and the editor to consider and review a substantially revised manuscript relative to the initial submission. Below, we provide a response and associated edits to the one comment raised by Reviewer #2. First, we will address two very minor corrections that emerged from ongoing work on a follow-up study to this one, which have no substantive impact on results or conclusions. All line numbers referenced below refer to line numbers in the *tracked changes* version of the manuscript.

<u>Minor Edits Unrelated to Review</u>

1) **Small fix to observed composite DSDs**
   First, we found a very small issue with the observed DSDs that is notable at the smallest size bins for the 2DS10 and HVPS instruments. This issue does *not* pertain to the FFSSP, which was used as the exclusive in situ instrument in Figs. 5, 7, and 8. This issue is most easily shown in a side-by-side comparison of the old and revised Fig. D1 (provided below), which shows the individual DSDs for each instrument as well as the composite used in Figs. 9-10. As shown, a correction to the bin normalization increased the values in the smallest bins (mainly for the 2DS10). The correction provides a better agreement between the instruments in overlapping size ranges. *Importantly, because the instruments were stitched together generally at sizes such that the smallest bins of a given instrument were already neglected in compositing, this makes very little difference in the composite DSDs that were used for analysis in Figs. 9-10*. In the revised manuscript, we therefore include corrected versions of Fig. D1 and Figs. 9-10, but the differences in the latter result in no quantifiable or qualifiable changes needed to the discussion of that analysis. The discussion of Fig. D1 in Appendix D was slightly modified to appropriately discuss the new figure (lines 813-818 in the tracked-changes manuscript).

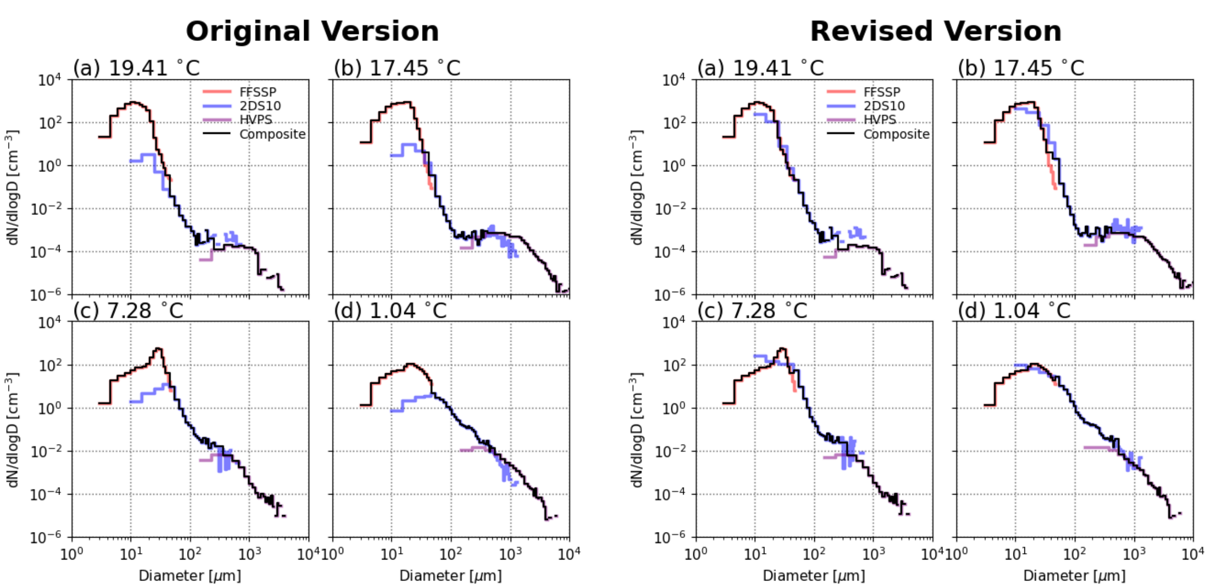

Fig. R1. Original (left) and revised (right) versions of Fig. D1 from the manuscript demonstrating a fix in bin normalization for the 2DS10 and HVPS instruments.

2) Additional Description of Modified Large-scale Vertical Motion for Bulk vs. Bin Simulations

We were reminded of a key distinction that needed to be declared regarding the large-scale vertical motion profiles. In previous versions of the manuscript, we neglected to explain that the positive vertical motion below 5 km (shown as a maximum of 2 cm s^{-1} in the original Fig. 3) was adjusted to be a maximum of 3 cm s^{-1} for the bin simulations. This was decided based on numerous sensitivity tests in which the magnitude of the lower troposphere dipole largely acted to modulate the timing of precipitation onset and thus system evolution. As shown in Fig. 6 of the manuscript, the target onset of substantial precipitation production was ~ 6 hrs, which allowed sufficient time for the system to reach peak precipitation production between 9 and 12 hours when the majority of the analysis was performed. For numerous compounding reasons, precipitation onset in the bin scheme was delayed relative to the bulk scheme when using the same large-scale vertical motion profile, and thus a stronger profile was used for the bin simulations to achieve relatively similar precipitation onset with the bulk scheme.

To address this, we have modified Fig. 3 (provided below for convenience) to show the additional profile of large-scale vertical motion below 5 km used for runs with the bin scheme, and have edited the text on Lines 246-249 (tracked changes version) to include this explanation and justification. While it would be possible to include an additional Appendix item describing these sensitivities, we ultimately find them unnecessary for an already lengthy manuscript and based on the justification that constraining large-scale dynamics was not a primary objective of this study, but rather to evaluate microphysics in a congestus system with reasonable evolution.

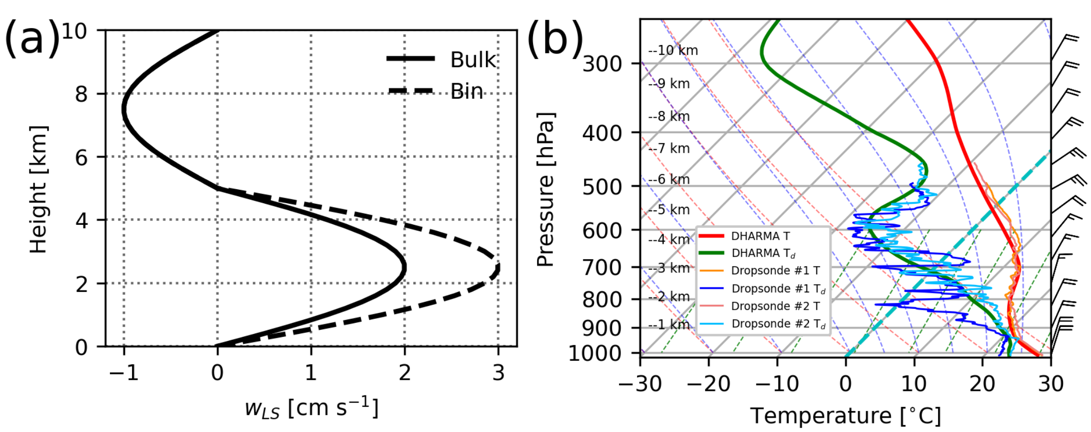

Fig. R2. Modified version of Fig. 3 from the manuscript showing the addition of the large-scale vertical motion line used for bin microphysics runs (dashed line).

Response to Reviewer #2

Overview & Comment:

"The authors present in this paper observations of microphysical properties (droplet size, concentration and DSD shape) in tropical cumulus congestus obtained at cloud top with the Research Scanning Polarimeter (RSP), and in-cloud with the fast forward-scattering spectrometer probe (FFSSP) obtained during the CAMP2Ex experiment. They compare these to a set of large-eddy simulations varying different properties of the microphysical scheme (bulk vs bin microphysics, different bulk schemes, turbulence, and aerosol profile). Thermals were also tracked in the LES to follow how microphysical properties evolve over time.

The paper reads well, the figures are clear and the authors discuss very well the limitations and difficulties of constraining the case they present. I believe the paper to be worthy of publication in ACP.

My only comment would be regarding nu_eff in the simulations: is it actually measuring the broadness of the distribution, or is it measuring its bimodality? Looking at Fig. 9-10, nu_eff has a plateau around 10-100 µm, where it is measuring the broadness of the cloud mode. It rapidly increases near the second mode – the vertical axis is cut off early, but my guess is that it plateaus again after the integral upper bound has passed most of the rain peak, and nu_eff then measures the broadness of the entire DSD. In that regard, I don't think LES values of nu_eff outside of the first or the second plateau are particularly meaningful: they simply measure the presence of a second mode in the DSD relative to an arbitrary size of 100 µm (or 50 µm, as the authors underline). My question would be then: how does this work for the RSP? Since the values reported on Fig. 7 e-f are all below ~0.3, is it much less sensitive to the presence of that peak? I believe some discussion on that would help better understand the apparent discrepancy between measurements and simulations."

Response:

We appreciate the reviewer's insightful comments regarding the evaluation of simulated effective variance (ν_{eff}). To provide further clarity, we include revised versions of Figs. 9 and 10 below (labeled Figs. R3 and R4), in which the cumulatively integrated ν_{eff} (bottom row) is displayed on a logarithmic scale. This better reveals the evolution of ν_{eff} into the rain mode.

The reviewer was correct in noting that, for the bulk scheme, ν_{eff} plateaus to a value representative of the full DSD, particularly once the rain mode is included. In contrast, for the bin scheme—especially under colder conditions where DSDs are broader—ν_{eff} increases more gradually with size, without a clear plateau distinguishing cloud and rain modes.

To directly address the reviewer's question of whether ν_{eff} reflects DSD broadness or bimodality: the answer is both. Plateau values of ν_{eff} can signal the presence of distinct cloud and rain modes, particularly in the bulk scheme and to a lesser extent in the bin scheme at lower altitudes. However, we emphasize that the plateau value of ν_{eff} within the cloud droplet size range remains a useful relative measure of the DSD's breadth. This is most evident in the bin scheme (Fig. R4), where the cloud mode in the simulated DSDs (top row) is clearly broader than in observations. The cumulatively integrated ν_{eff} reflects this, increasing more rapidly with size and reaching a higher plateau compared to observations—especially apparent in the previously used linear scale. This interpretation is supported by Fig. 7, where bin-simulated "in situ" profiles show higher ν_{eff} at lower altitudes compared to observations, while the bulk scheme agrees more closely—consistent with results in Fig. 9.

In response to the reviewer's suggestion that differences in retrieved and simulated cloud-top ν_{eff} may result from the simulated "retrieval" method sampling more of the drizzle/rain mode, we previously noted (lines 464–468 of the manuscript):

"Overall, the differences between simulated cloud-top and "in situ" ν_{eff} imply that cloud-top identification using Eq. 10 is rather sensitive to drops in the precipitation size range, even at and near cloud top and to a greater degree at the highest altitudes where both N_d and R_{eff} appear reasonably well reproduced. Indeed, decreasing the size cut-off for cloud-top distributions in Eqs. 8-10 from r = 100 μm to 50 μm significantly decreased the cloud-top ν_{eff} values for both CNTL and BIN_TURB_10X, but did not have a large impact on cloud-top N_d and R_{eff} (not shown)."

That said, we acknowledge that further speculation is warranted. In particular, we identify three plausible contributing factors, though they are not easily resolved within our current framework:

1. **Instrument sensitivity limitations**: The truncation size threshold used to mimic the RSP is necessarily idealized (e.g., fixed at 100 μm), whereas in reality, the RSP's size sensitivity depends on the extinction properties of the sampled cloud scene.

2. **Cloud-edge resolution in LES**: The model may inadequately resolve sharp cloud-top gradients, allowing drizzle-sized particles to exist near cloud top more frequently than observed.

3. **Homogeneous mixing assumption**: The simulations assume homogeneous mixing during entrainment, preserving droplet number and allowing larger, slowly evaporating droplets to persist near cloud top. This may contribute to artificially broad DSDs within the size range visible to the RSP.

The first two points were already discussed at various points in the manuscript (e.g., lines 466-468, 470-472, 738-740), but we have added the following to lines 477-481 of the revised manuscript as an extension of the paragraph that already discusses potential reasons for these discrepancies:

> "Another plausible explanation for the substantially larger cloud-top ν_{eff} in simulations at higher altitudes may be related to the model's enforced assumption of homogeneous mixing at subgrid scales, whereby droplet number is preserved

during entrainment. This may allow a broader range of relevant droplet sizes — including large, slowly evaporating ones — to persist near cloud top, leading to artificially broad DSDs within the RSP's sensitive size range."

Lastly, we have replaced Figs. 9 and 10 with the updated versions (Figs. R3 and R4 below) using logarithmic scaling for cumulatively integrated ν_{eff} to better illustrate these points. To accommodate this slight modification and clear up some of the discussion, the discussion on lines 564-575 and 587-594 has also been modified.

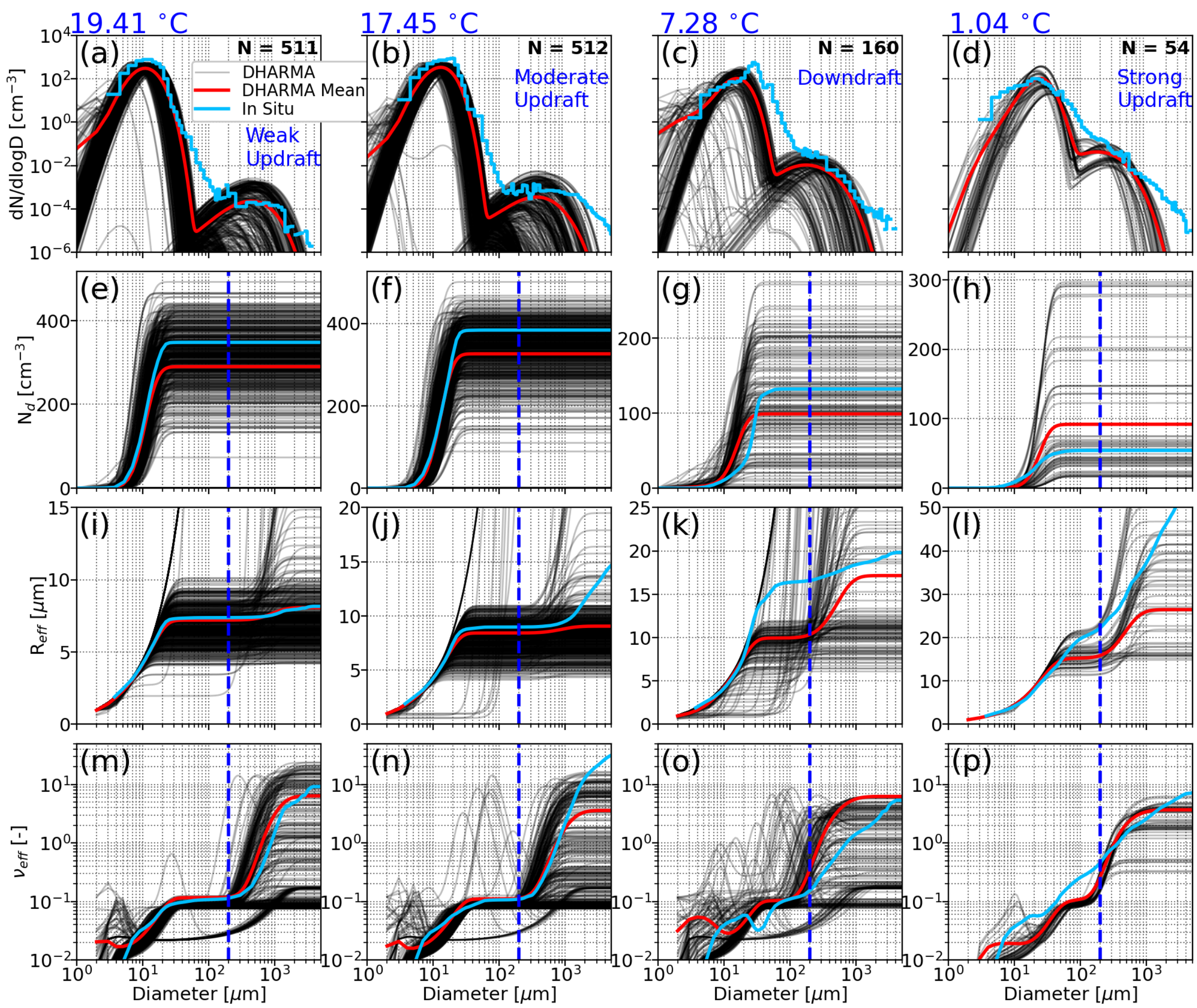

Fig. R3. Modified version of Fig. 9 from the manuscript that sets the y-axis of effective variance (bottom row) to logarithmic scaling.

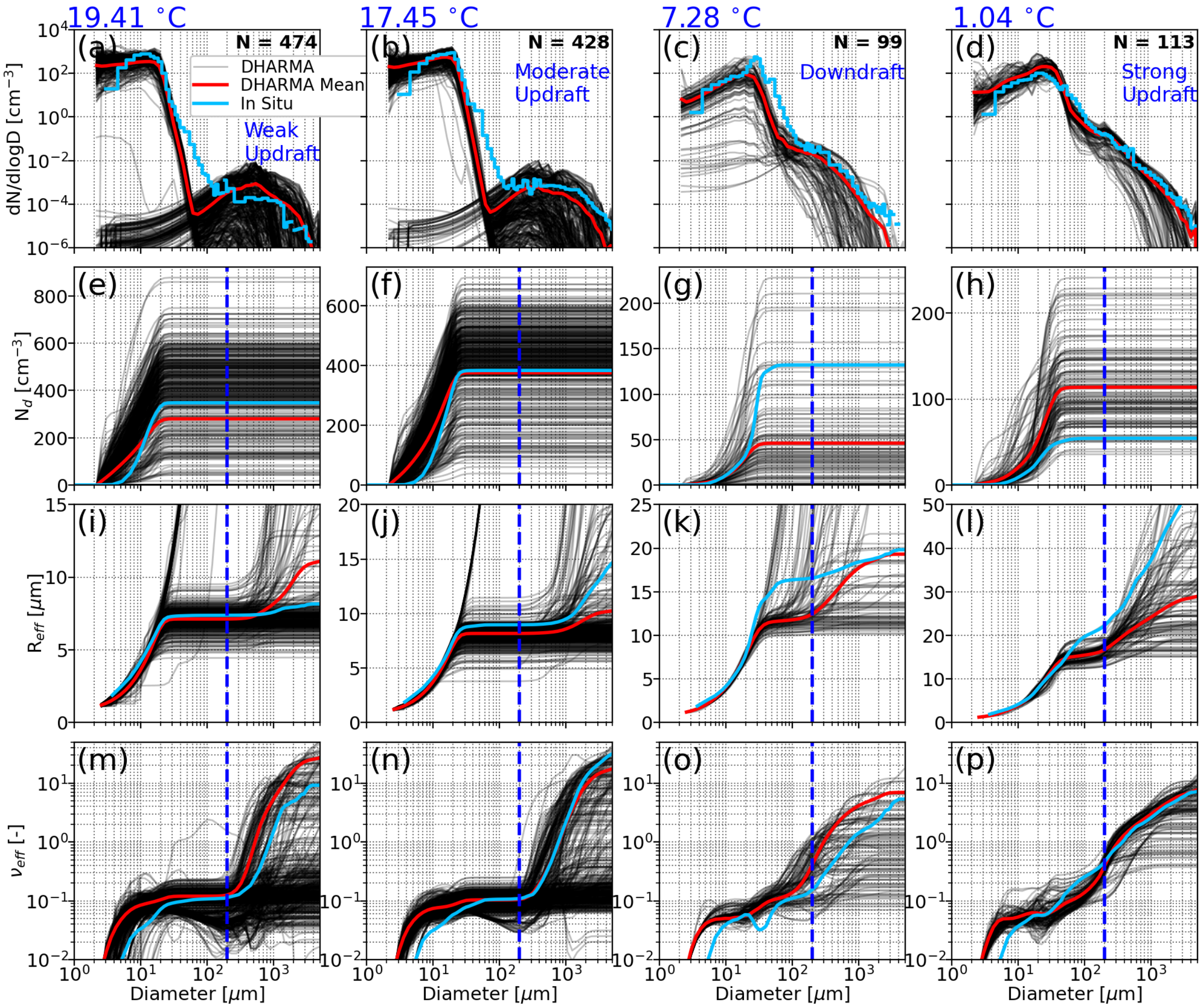

Fig. R4. Modified version of Fig. 10 from the manuscript that sets the y-axis of effective variance (bottom row) to logarithmic scaling.