Reviewer comments on *Why Is Height-Dependent Mixing Observed in Stratocumulus?*

This manuscript examines how to interpret homogeneous versus inhomogeneous mixing (HM/IM) signatures in stratocumulus, integrating insights from in-situ observations and modeling with a framework that explicitly resolves inhomogeneous mixing. This manuscript provides a clear demonstration that the frequently reported IM near cloud top and HM deeper in cloud can arise as a collective signal from parcels with distinct entrainment–evaporation histories, rather than a true local mixing mode. It offers a compelling reframing of bulk versus local perspectives. The goals and message are clear, and the results have practical value for the community by informing the design and interpretation of in-situ aircraft measurements as well as LES/Lagrangian modeling strategies to diagnose entrainment and mixing in stratocumulus clouds. I find this a valuable contribution and suitable for prompt publication after revision. I recommend addressing several points of clarification in the discussion and adding a small set of targeted sensitivity tests.

Response: We thank the reviewer for the positive evaluation and encouraging remarks on our work. We also appreciate the thoughtful suggestions, which have greatly improved the completeness of the manuscript. Detailed responses to each comment are provided below.

Comment 1:

The time evolution of the standard deviation of δqv in Fig. 8 is highly informative. However, as the authors note, post-entrainment descent is the more realistic pathway in marine stratocumulus. I therefore suggest presenting the same diagnostics for a descending (non-isobaric) configuration (e.g., the Control experiment) to assess how adiabatic warming during descent modifies both the characteristic reaction time and the HM IM transition. This would further help LES and Lagrangian trajectory studies that have adopted fixed-lag windows for mixing diagnostics (e.g., Lim & Hoff- mann, 2023, 2024), in non-isobaric conditions.

Response: We thank the reviewer for this insightful comment. In the revised manuscript, we have included the time evolution of the standard deviation of δq_v for the *Control* experiment, as shown in Figure 4a. The corresponding discussion has been added to the revised text.

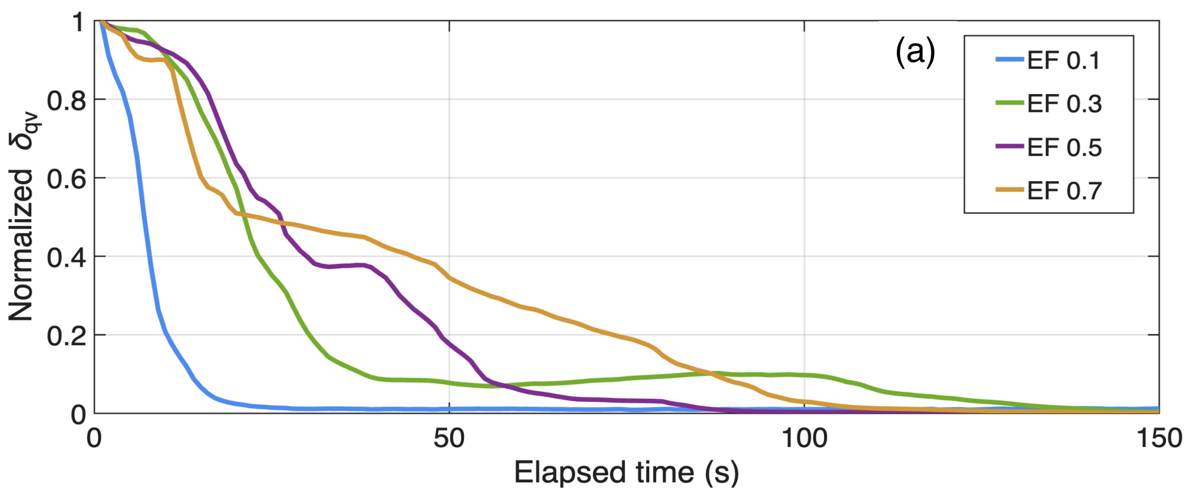

Figure 4a: Normalized standard deviation of water vapor (δ_{qv}) in the parcel after entrainment for the control experiment. The blue, green, purple and yellow line represents the parcel with EF of 0.1, 0.3, 0.5 and 0.7.

Line 339: "…The normalized standard deviation of water vapor is plotted to illustrate the temporal evolution of the mixing process in the Control experiment (Fig. 4a). The standard deviation of water vapor (δq_v) is calculated at each time step within the one-dimensional domain (20 m in length with a 1 mm grid spacing) and normalized by its value at 1 s after entrainment. The evolution of δq_v reflects the characteristic mixing timescale (Tölle and Krueger, 2014). As shown in Fig. 4a, δq_v peaks immediately after entrainment and decreases over time as mixing between entrained and cloudy air proceeds. Parcels with smaller entrainment fractions (EF) exhibit shorter mixing times than those with larger EF; for example, a parcel with EF = 0.1 reaches equilibrium after roughly 20 s, whereas one with EF = 0.7 requires about 100 s to homogenize water vapor within the domain.

Line 348: "…In the Control configuration, the parcel descends immediately after entrainment at a constant velocity of −1 m s^{-1}, allowing elapsed time to be directly related to distance below the cloud top. Accordingly, three representative height levels: 5 m, 50 m, and 200 m below the cloud top, are selected to characterize distinct stages of the mixing process…"

Comment 2:

The authors use a monodisperse NaCl aerosol initially and CCN-free entrained air. While this isolates sampling effects, many studies show that entrained aerosols and the pre-mixing droplet size distribution (DSD) shape strongly govern the relative changes in N and r, and thus the HM/IM di- agnostics (Krueger et al., 2008; Luo et al., 2022; Lim & Hoffmann, 2023). In particular, broader spectra with many small droplets can favor N reductions via complete evaporation, altering the n–r3 change. Please either add sensitivity results or, if out of scope, expand the discussion to explain the expected impacts and identify this as a priority for follow-up.

Response: We thank the reviewer for the constructive suggestion. In the revised manuscript, we have added a *CCN-Entrained-Air* experiment, in which the entrained air contains dry aerosols from the free atmosphere that can act as CCN. The results show a consistent transition from IM near the cloud top to HM deeper within the cloud, similar to the control case. In addition, a reduction in mean droplet size and an enhanced HM signature are observed under CCN entrainment, consistent with previous studies (Luo et al., 2021; Lim and Hoffmann, 2023). A detailed description of the experimental setup is provided in **Table 1**, and the corresponding results are presented in **Figure 5**.

Table1 – Model Configuration

Parameter	Control	Dry Entrained Air	Enhanced Turbulence	CCN Entrained Air	Reduced Velocity
Domain Length (m)			20m		
CCN Concentration (cm^{-3})			80		
Cloud Top Height (m)			950		
Aerosol Size Distribution			Monodisperse		
Initial solute mass (kg)			$0.1122*10^{-17}$		
Initial aerosol radius (m)			$0.216*10^{-6}$		
Type of aerosol			NaCl		
Eddy Dissipation Rate (m^2s^{-3})	0.0025	0.0025	0.01	0.0025	0.0025
Entrained air temperature (K)	285.77	288	285.77	285.77	285.77
Entrained air water vapor (g/kg)	8.6	7.9	8.6	8.6	8.6
Entrained CCN in the dry air	N	N	N	Y	N
Vertical Air Velocity (ms^{-1})	±1	±1	±1	±1	±0.5

Table 1: Model configurations for the control, dry and turbulent simulation experiment.

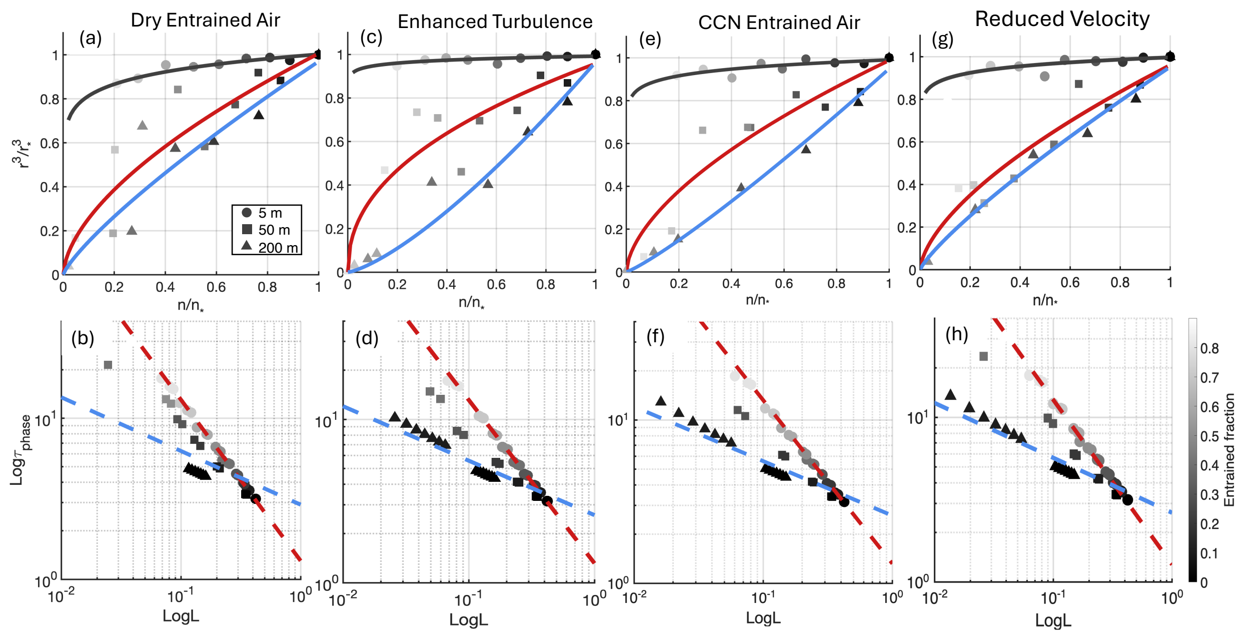

Figure 5: Same as Figure 4, but for the four sensitivity experiments: (a)–(b) correspond to the Dry-Entrained-Air experiment; (c)–(d) to the Enhanced-Turbulence experiment; (e)–(f) to the CCN-Entrained-Air experiment; and (g)–(h) to the Reduced-Velocity experiment.

Line 151: "…In addition to the control case, four sensitivity simulations were conducted to evaluate the robustness of the experimental design. The Dry Entrained Air experiment represents the scenario in which the entrained air is drier. Specifically, the model setup is the same as the control one except the entrained air property is estimated using the parcel at 20 m above cloud top experiencing adiabatic descent to cloud top. The selection of the distance of the entrained parcel from cloud top is arbitrary and does not affect the conclusions of this study. The Enhanced Turbulence experiment simulates strongly turbulent environment with EDR set to 0.01 m^2 s^{-3}. The CCN entrained Air experiment allows the entrained air containing dry aerosols entrained from free atmosphere. The properties and concentrations of the entrained aerosols are identical to those initially specified within the parcel. …"

Line 406: "…In the CCN-Entrained-Air experiment (Fig. 5e, f), the normalized r^3 values for each normalized number concentration are smaller than those in the control case, indicating a more pronounced reduction in droplet size. This feature reflects a stronger HM tendency under CCN entrainment, consistent with previous findings that activation of entrained CCN broadens the droplet size distribution toward smaller droplets and amplifies the characteristics of homogeneous mixing (Lim and Hoffmann, 2023; Luo et al., 2022). …"

Line 422: "…Overall, despite variations in the thermodynamic and dynamic properties of the entrained air, all simulations consistently exhibit an IM signature near the cloud top and a transition toward HM within the cloud, with an increasing degree of HM deeper into the cloud layer. These model-based results align well with aircraft observations in stratocumulus clouds (Yum et al., 2015; Yeom et al., 2021), providing a robust basis for the more detailed analysis presented in the following section…"

Comment 3:

Parcels in real clouds often dwell near the cloud top for a short time after entrainment before descending. Please add a dwell-then-descent variant in which the post-entrainment velocity is held at $w = 0$ for a prescribed τdwell (tens of seconds) and then switched to the descending value used in Control. It would be useful to clarify whether this pathway yields a stronger HM or IM signal in both the local and bulk perspectives. Moreover, the local HM to IM interpretation may partly reflect insufficient time for droplets to respond, where mixing diagnostics require adequate time for both scalar mixing and microphysical adjustment. The current mixing-diagram framework should explicitly acknowledge this timescale dependence. I therefore recommend adding a short discussion on how analysis-window length and parcel dwell affect the local perspective of the mixing process.

Response: We thank the reviewer for this insightful suggestion. Following the recommendation, we implemented a *dwell–then–descent* modification in the *CCN-Entrained-Air* experiment for the reviewer. In this test, parcels remain stationary at the cloud top ($w = 0$ m s^{-1}) for 10 s before descending. The corresponding analyses are shown in **Figure 1** below for the reviewer's reference. As illustrated in **Figure 1c**, introducing a dwell period at the cloud top produces a stronger HM signature and a larger reduction in droplet radius, consistent with enhanced evaporation and mixing during the dwell phase. This supports the interpretation that extended residence time near the cloud top allows more complete droplet adjustment and thus strengthens local HM characteristics. Nevertheless, the overall transition from IM near the cloud top to HM deeper within the cloud remains evident, as shown in the log(L)–log(τ_phase) diagrams (Fig. 1d).

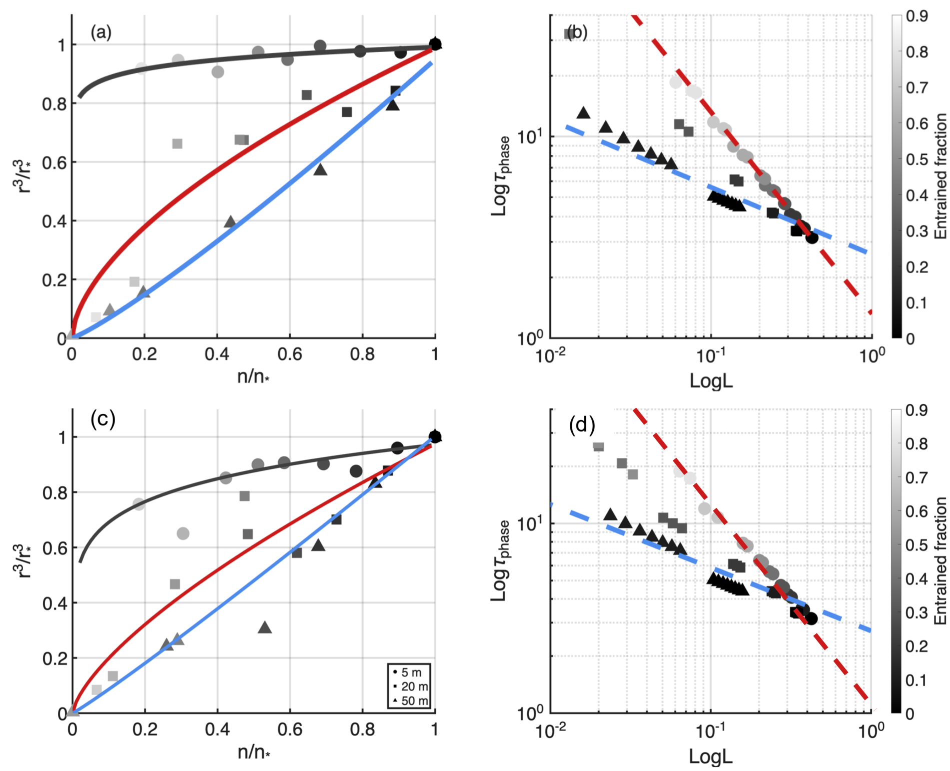

Figure 1 for reviewer (bulk perspective). Mixing diagrams for (a)–(b) the *CCN-Entrained-Air* experiment and (c)–(d) the same case with a 10 s dwell at the cloud top prior to descent. The dwell period enhances the HM signature near the top but preserves the overall IM-HM transition with cloud.

The parcel-based mixing diagrams (**Figure 2**) show only minor differences between runs with and without the dwell period. Both exhibit an HM tendency near the cloud top, followed by an increasing trend toward IM influence with depth.

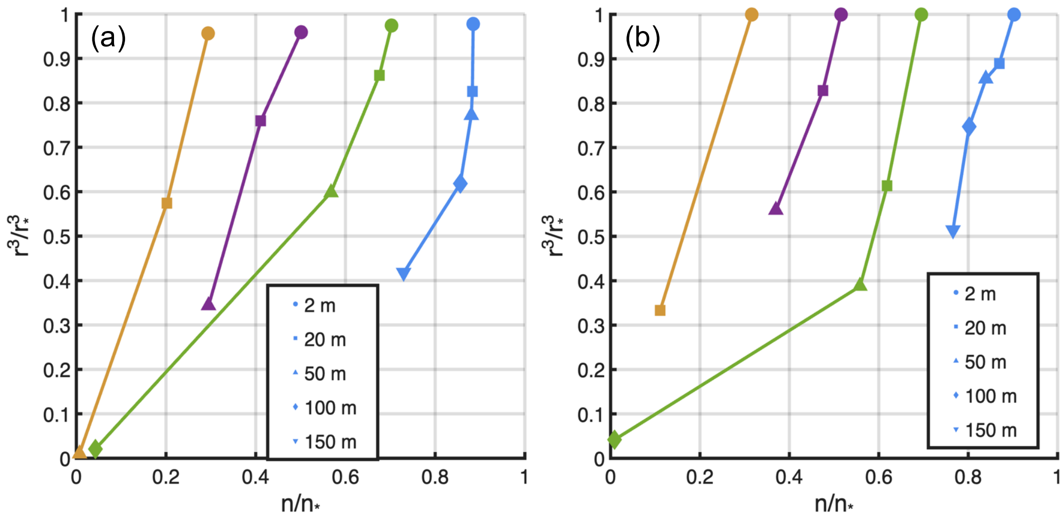

Figure 2 for reviewer (local/parcel-based perspective): Local mixing diagram for (a) experiment with entrained CCN, and (b) same case with dwell time of 10s at cloud top before descent.

Additionally, as suggested by the reviewer, we have added more discussions on the local perspective of the mixing process in the revised manuscript:

Line 617: "…Finally, it is noted that this study primarily aims to explain the IM–HM transition within cloud as observed from the bulk perspective. We do not attempt to draw conclusions about the local (e.g. parcel-based) mixing state within cloud. The local mixing behavior can vary depending on the model configuration and analysis approach, and it is strongly influenced by the timescale over which droplet properties (i.e. size and number) adjust following entrainment. For instance, in real cloud parcels may briefly dwell near the cloud top before descending, and the inferred local mixing characteristics therefore depend on this residence time. A longer dwell time near cloud top would permit greater vapor–droplet interaction at cloud top, potentially altering the local mixing signature with depth. A detailed investigation of these time-dependent local mixing processes is beyond the scope of this study…"

Grammar and Typo

- It seems like the unit of entrained air water vapor is wrong. $8.6*10^{-3}$ g / kg seems to be too small.
- In Line 17, the IH characteristic should be the IM characteristic.
- Sometimes, ψand ϕare mixed when referring to the homogeneous mixing degree (e.g., Fig. 5). Please fix this for consistency.

Response: We thank the reviewer for the careful and detailed comments. All identified issues have been corrected in the revised manuscript.

References

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