Response to Editor

Please respond to the final comments made by reviewer #2. They raise legitimate concerns regarding the rather stringent conditions considered in this study. I believe that you can address these concerns with additional caveats added to the paper. In particular, the abstract should identify the idealized steady state nature of the simulations, particular focus on coupled boundary layers, and emphasize that precipitating conditions were not considered.

We thank the editor for the additional comments. Our answers to Reviewer 2 can be found below. We added an additional statement to the abstract to revised manuscript to highlight the idealized nature of our study: *"Using this idealized framework that neglects interactive surface fluxes, changes in boundary layer depth, or the diurnal cycle of solar radiation, we are able to show that cloud-water adjustments weaken distinctly from dln(L)/dln(N)=-0.48 at N=100 cm^{-3} to -0.03 at N=1000 cm^{-3}, indicating that a single value to describe cloud-water adjustments in weakly and non-precipitating clouds is insufficient."*

Response to Reviewer 2

We thank the reviewer for the additional comments on our manuscript.

My main major concern remains: the extent of constraining assumptions does not allow for realistic responses and the results are only applicable in an extremely narrow set of circumstances. I explain my thoughts a bit more deeply in the PDF and provide some mathematical explanations for why I feel this why. Instead of focusing solely on the entrainment rate treatment in the mixed layer model context, I think the study would benefit from the use of a full MLM, which would broaden the scope of the results to include conditions that may be more common in nature.

We agree with the reviewer that this study is idealized. However, this study's primary goal is to increase our conceptual understanding of negative cloud-water adjustments in weakly and non-precipitating stratocumulus. Previously, most studies showed a large variety of constant slopes to describe negative cloud-water adjustments (e.g., Fig. 1 in Glassmeier et al. 2021). Our study clearly shows that the slope is a function of the droplet concentration and might explain why literature values differ so much. As stated before, this study does not aim for an exact quantitative description of the underlying physics, but a better qualitative understanding. As suggested by the editor, we now emphasize the idealized nature of our study also in the abstract: *"Using this idealized framework that neglects interactive surface fluxes, changes in boundary layer depth, or the diurnal cycle of solar radiation, we are able to show that cloud-water adjustments weaken distinctly from dln(L)/dln(N)=-0.48 at N=100 cm^{-3} to -0.03 at N=1000 cm^{-3}, indicating that a single value to describe cloud-water adjustments in weakly and non-precipitating clouds is insufficient."*

The statement "This study was built upon the assumption that an increase in entrainment rate (we) due to an increase in N is exactly offset by a commensurate decrease in L, resulting in the same we irrespective of N" has the following implication:

$$\frac{dw_e}{dN} = 0, \tag{1}$$

with the chain rule expansion resulting in

$$\frac{dw_e}{dN} = \frac{\partial w_e}{\partial N} + \frac{\partial w_e}{\partial L}\frac{dL}{dN} = 0. \quad (2)$$

Rearranging the above equation gives

$$\frac{dL}{dN} = -\left(\frac{\partial w_e/\partial N}{\partial w_e/\partial L}\right). \quad (3)$$

Eq. 3 then imposes the following behavior on the slope parameter (m),

$$m = \frac{dln(L)}{dln(N)} = \frac{N}{L}\frac{dL}{dN} < 0. \quad (4)$$

This assumption results in a strong constraint on the slope parameter that vastly decreases the utility of the analysis.

We agree with this analysis. However, the negative cloud-water adjustments that we postulate are based on many studies on aerosol-cloud interactions that have shown that this entrainment-related effect exists (e.g., Fig. 1 in Glassmeier et al. 2021). Our study wants to show what conclusions can be drawn when using it as a starting point.

Entrainment rate would be expected to change as a function of N, and the assumption that L exactly and immediately compensates any N-related entrainment changes is questionable, given that the companion study required nearly 18 hours to equilibrate, which is far more than a single nighttime period. Clouds in nature would likely never have time to fully equilibrate overnight before diurnally varying solar insolation muddies the picture. The dependence of Eq. 1 on there being a perpetual night calls the entire study into question. Additionally, neglecting cloud deepening/thinning, fixed surface fluxes, and restricting the analysis to nighttime conditions are fundamental weaknesses of the study that results in decreased relevance to any real world scenario. While the authors mention that adding complexity would complicate the analysis, there are many ways to account for these processes within the MLM framework using moisture, energy, and mass budgets. One of the three main results pertains to the evaporation of precipitation, which introduces an internal inconsistency into the study. Virga decreasing we is not compatible with Eq. (1), since this complicates the direct relationship between N, L, and we and would allow for Eq. 4 to be positive in precipitating cases. It is not clear from Fig. 1 and 2 which cases have virga and which ones don't. This would be a helpful addition to the plot and help determine just how big of an issue the virga-mediated entrainment feedback may be.

Again, we agree with these thoughts for the most part. However, we would like to reiterate that we do not believe that the evaporating virga creates an external inconsistency, as we made sure that losses of cloud water to the surface are negligible: *"Since our approach does not consider losses in L due to surface precipitation, we neglect regions of the L-N phase space that are substantially affected by this process. The dashed line marks the surface precipitation rate $P_p(0)=0.1\ w'q_t'|_0\ \varrho_0 = 0.3$ mm d^{-1}. By determining this value based on $w'q_t'|_0$, we identify regions of the L-N phase space in which precipitation losses are substantial (to the left of the dashed line) and the region where precipitation losses are negligible, i.e., the weakly and non-precipitating clouds that are the main focus of this study (to the right of the dashed line)."* The effect of virga can be easily determined from Fig. 2e, which clearly shows the extent of the analyzed phase space (right of the dashed line) that is affected by virga. By deactivating the influence of virga (green continuous line), Fig. 3a clearly shows what part of the phase space is affected.

Overall, the extent of constraining assumptions does not allow for realistic responses and the re- sults are only applicable in an extremely narrow set of (unlikely/unnatural) circumstances. I don't believe the results significantly advance our previous understanding of sedimentation-entrainment feedbacks and I believe that the virga results contradict the assumption in Eq. 1 and could theo- retically result in positive m.

As stated above, the virga considered here does not substantially affect the cloud-water budget. We agree that stronger precipitation results in positive cloud-water adjustments, as previously shown by Albrecht (1989) and others, and usually referred to as "precipitation suppression", where an increase in N results in smaller cloud droplets that do not collide as frequently and hence produce less precipitation, that would remove cloud water from the system through surface losses. By focusing on virga, in which only negligible amounts of cloud water reach the surface because it almost completely evaporates below cloud base, the total water of the system is only marginally affected by this form of precipitation. However, our study clearly shows that the effect of the evaporating virga has implications for the buoyancy produced by the boundary layer (Figs. 1d, 2e, and 3a). To our knowledge, this effect has not been fully recognized in the community's discussion on cloud-water adjustments. Thus, our study should be seen as an incentive for future work on this topic, as we cannot answer all questions on this issue due to its idealized nature. In the last version of the manuscript, we highlighted the idealized nature of our study in several locations: *"All in all, this study showed that even comparably simple models, such as the one used here, can be applied to increase our fundamental understanding of aerosol-cloud interactions. In fact, the simplicity of the applied model allowed us to directly link cause and effect of cloud-water adjustments, which can be difficult in more complex models such as global circulation or even large-eddy simulation models due to confounding factors (Mülmenstädt et al., 2024). That being said, the nuance provided by these models should not be disregarded as they help to quantify the effects that have been neglected here (e.g., interactive surface fluxes, changes in boundary layer depth, or the diurnal cycle of solar radiation). Thus, we advocate that the assessment of aerosol-cloud interactions should balance the use of complex and simple approaches by substantiating quantitative understanding with qualitative insight."* and *"Additionally, (35) does not consider adjustments in surface fluxes (Bretherton and Wyant, 1997), as well as the impact of solar radiation (Chen et al., 2024b), for which more complex models would be required. Nonetheless, the large-eddy simulations presented in our companion paper (Chen et al., 2024a) indicate that sufficient physics are captured in (35) to yield reasonable insights, as we will detail below."* In the revised version, we also emphasize this idealized nature in the abstract, *"Using this idealized framework that neglects interactive surface fluxes, changes in boundary layer depth, or the diurnal cycle of solar radiation, we are able to show that cloud-water adjustments weaken distinctly from dln(L)/dln(N)=-0.48 at N=100 cm^{-3} to -0.03 at N=1000 cm^{-3}, indicating that a single value to describe cloud-water adjustments in weakly and non-precipitating clouds is insufficient."*