Revision of

‘Modeling the Coupled and Decoupled states of Polar Boundary-Layer Mixed-Phase Clouds ’

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This document contains the response to the editorial review of ‘Modeling the Coupled and Decoupled states of Polar Boundary-Layer Mixed-Phase Clouds’ submitted to EGUSPHERE for possible publication in Atmospheric Chemistry and Physics. Comments from the Editor are in black and responses are in blue.

Comment :

« This is an interesting paper, that was evaluated slightly differently by the two expert reviewers, that were challenging the authors on both details, concepts and context. First I'd like to thank the reviewers for diligent work. Second, my judgment is that the authors have in principle responded adequately to both critique and questions, and made substantial changes to the manuscript; this work should be published - soon. I have only one minor request. »

We sincerely thank the editor for the positive comment regarding our revision work.

« This relates to the RH profiles in Figure 2, where in the original manuscript RH_liq profiles were well above 100%; not just a "few %". In most modeling, clouds would form at RH_liq < 100% to account for sub-gridscale variability assuming that pockets of air can become supersaturated at a substaurated grid volume average. In the revised manuscript this problem is fixed by taking out the RH_liq profiles and only showing RH_ice, that can easily become > 100%. I would like to see a properly calculated RH_liq profile, because that is what you can compare to the observations, and would also like a better explanation for why the originally plotted RH_liq could exceed 100%, because I did'n get the previous one and it did feel more like an excuse than an explanation. »

This is indeed a delicate point and we apologize for not being clear enough in our previous response.

In LMDZ, the state variables of the model are the specific water contents and the temperature. Relative humidity is a diagnostics variable. In convective boundary layers, the formation of liquid clouds is made through adjustment considering the saturation deficit variable $s=a*(q-q_{sat,l}(T_l))=q-q_{sat,l}(T)$, a being a thermodynamical function and T_l the liquid temperature. Cloudy (liquid) air parcels thus correspond to the part of the subgrid (gaussian) distribution of s that exceeds 0.

The variable s has been chosen (see Sect. 2.3 in Jam et al. (2013)) as its distribution in convective boundary layer (observed or simulated in LES) makes it possible to distinguish the two populations or air parcels that is, those belonging to the convective updrafts and those of the environment. Moreover, and line with the beginning of your comment, clouds form when the mesh-averaged s is lower than 0 (because part of the distribution exceeds 0). However and importantly, s is a humidity variable that is not a linear function of RH_{liq}. This is exactly where the problem comes out as we cannot easily estimate the subgrid distribution of RHliq, knowing that of s. In other words, we assume a subgrid distribution of s, thus we know the mesh-averaged s, but we cannot properly calculate the mean RHliq.

Of course such a problem does not come out in models that do not consider a subgrid distribution of humidity (whatever the humidity variable) such as CRMs. In such models, when the cloud liquid water forms through saturation adjustment, the relative humidity wrt liquid is necessarily 100 %.

To diagnose RHliq, we thus necessarily have to make assumptions. By default (and this is what we showed in the first version of the paper), we compute a variable <RHliq> which is the ratio between the mean specific humidity [q] in the mesh and the saturation specific humidity at the mean temperature of the mesh qsat([T]). Here [] denote the mesh-average. However in convective boundary layers, q and $q_{sat}(T)$ are inversely correlated. In updrafts, air is moister and warmer compared to the environment (q is high and $q_{sat}(T)$ is high) and vice versa in the environment. Subsequently, the mean ratio if lower than the ratio of the means namely, $[RH_{liq}]<[q]/qsat[T]=<RH_{liq}>$. Hence the fact that we had $<RH_{liq}>$ values exceeding 100 % in the first version of the paper.

This then raises the question of how to robustly address your comment and demonstrate a *properly calculated RH_liq profile*, given that we cannot—at least in theory—diagnose one that is consistent with the subgrid distribution of *s*. This issue was something we considered at length during the previous revision round (hence the final decision—which we agree is not fully satisfactory—to remove the RH_liq profiles).

Unfortunately, such a request is not possible with the current version of the model as we would need to modify the cloud scheme and work with subgrid distributions of RH. Note that this is what we will be doing for cirrus clouds (Borella et al. 2025) but not for boundary layer clouds. After some thoughs, we think that the most consistent way to go is to show <RHliq> in clear sky regions, and impose a value of 100 % when the mean saturation deficit is higher than 100 % wrt liquid. This is now what we show in the new version of the paper. The caption of Figure 2 has been modified accordingly. Note that the liquid layer in the simulation now corresponds to a layer where RHliq = 100 %.

Borella, A., Vignon, É., Boucher, O., Meurdesoif, Y., and Fairhead, L.: A New Prognostic Parameterization of Subgrid Ice515Supersaturation and Cirrus Clouds in the ICOLMDZ AGCM, Journal of Advances in Modeling Earth Systems, 17, e2024MS004 918,https://doi.org/10.1029/2024MS004918, e2024MS004918 2024MS004918, 2025

Jam, A., Hourdin, F., Rio, C., and Couvreux, F.: Resolved Versus Parametrized Boundary-Layer Plumes. Part III: Derivation of a Statistical Scheme for Cumulus Clouds, Boundary Layer Meteorology, 147, 421–441, 2013