<u>Replay to the reviewers</u>

"What is adiabatic fraction in cumulus clouds: high-resolution simulations with passive tracer" by Eytan et al. 2021

We would like to thank the reviewers for their comments that helped us to improve and clarify the manuscript.

To address all the comments and remarks, the manuscript has been revised. We summarize below the novelties and the main modifications performed in the manuscript to clarify and strengthen the results:

1. The significance and applicability of the results are now emphasized and clearly stated.
2. The abstract and introduction were revised to emphasize that this is a theoretical study that compares different approaches that were used previously to calculate AF, and revisits some of their assumptions.
3. The summary and conclusions section was revised such that the take home message for calculating AF (e.g. list of points to consider) are summarized clearly.
4. The results are explained in a more detailed way now with additional information. For example; the effect of the toroidal vortex on the differences between AF and a conservable scalar.

- Point by point responses are presented below (in blue).

Reviewer 1:

Summary:

In this paper, the authors assess various methods used for estimating adiabatic fraction (AF) in a non-precipitating cumulus cloud. A High-resolution LES model with bin microphysics was used for simulating the cloud field. The AF computed using different methods was compared against the AF calculated using a passive tracer.

I am not convinced about the key results and conclusions that are drawn from this study. Additional details must be provided to understand the results and to assess the significance of this work.

Answer: Thank you for the detailed review. Additional details and explanations were added to the manuscript in order to address all the comments. Please see all the details in the answers below.

Major comments:

1. In section 2.3, the LWCad calculation in Eq. 5, 7 and 8 assume that the parcel under consideration is adiabatic. So, I am wondering how these equations can be used for calculating the adiabatic LWC from a cloud field that is affected by entrainment/mixing. The temperature and water vapor fields from the simulation will be affected by entrainment/mixing. So, using these fields in Eqs. 5, 7 and 8 would violate the assumptions used in deriving these expressions. Thus, the LWCad computed using the technique mentioned in this study would not be correct.

   Answer: As the reviewer rightly mentioned, using an adiabatic parcel model to estimate LWC_{ad} has its limitations since not all the parts of the simulated cloud (the higher levels for example) contain pure adiabatic parcels that can be used to calculate the adiabatic profiles. Hence, this issue was the first thing we addressed in the paper. In section 3.1 we show sensitivity tests of each method of LWC_{ad} calculation to the chosen profiles. Fig. 1 in the paper shows that the method we chose to use for the rest of the paper (AF_{ref} that is based on eq. 5,6) do not show significant sensitivity to the chosen profiles, partly because it is using two variables (specific humidity and temperature) that their mixing effects compensate one another. This is not the case in the other methods that are either using humidity (AF_{qt}, Eq. 7; in which mixing causes overestimation), or temperature (AF_{dtdz}, Eq. 8; in which mixing causes underestimation). In fig. A2 below (added to the revised appendix of the paper as fig. A2), we show the calculated LWC_{ad} profiles by the three methods: when using different subsets of voxels that were chosen by several thresholds on the passive tracer concentration (i.e. representing regions in the cloud in different dilution levels). Indeed, the figure shows that there are no pure undiluted parcels (represented by a threshold of $Tr>0.99$) above the inversion (curve of black dots), but, using the slightly diluted parcels (tracer>0.7) to estimate LWC_{ad} is not introducing large errors in our reference method (AF_{ref}). We note that the lowest threshold value that was used for the profiles presented in Fig. 1a-c was a tracer concentration of 0.67 in the highest levels of the simulation. This is not the case for the other methods (AF_{qt}, AF_{dtdz}; fig. A2b,c) that clearly show overestimation or underestimation of LWC_{ad}. The method that is based on a temperature profile (AF_{dtdz}) show smaller biases because the relative change in temperature between pure core and the environment is small (1-2 degrees change over a magnitude of ~290 K). This point is tightly related to comment No. 6 that suggests using the linear assumption with cloud base properties (as derived by Rogers and Yau, 1996). We would like to note that this derivation (that is tested in section 3.2.1) is using a strong assumption about the temperature and humidity profiles instead of estimating them, (i.e., that A_1/A_2 is constant with height). One of the goals of this paper is to revisit such assumptions and test their robustness. In the revised manuscript, we added figure A2 to the appendix of the paper and we rewrote parts of section 3.1 to make it clearer.

Line 171: *"The accurate estimations of the adiabatic vertical profiles of T and q_v were obtained here by averaging the values of those parameters in the voxels containing the highest 1% Tr values at each altitude (minimal threshold that was used was Tr=0.67 in the high levels of the cloud), and the results are presented in Fig. 1a-c. The cross-section of Tr is provided in Fig. 1d."*

Line 181: *"It is shown that AF_{ref} remains almost similar when using either the approximated or accurate profiles. On the other hand, AF_{qt} and AF_{dTdz} exhibit some underestimation and overestimation compared to the accurate profiles, respectively. These differences are explained in details below and sensitivity tests to the chosen profiles according to different thresholds on Tr values is presented in the appendix for all three methods (Fig. A2)."*

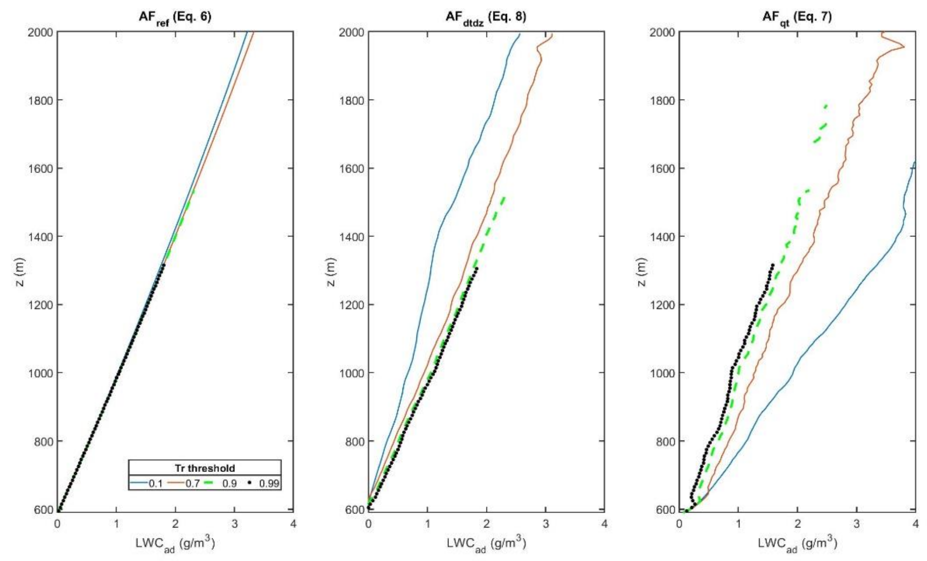

Figure A2. LWC$_{ad}$ profiles of different approaches for different estimations of adiabatic profiles. *LWC$_{ad}$(z) was calculated according to eq. 6* ***(a)****, eq. 8* ***(b)*** *and eq. 7* ***(c).*** *Taken from a snapshot of a cloud with aerosols concentration of 500 cm^{-3} at the time of maximal development (33 minutes). The temperature and humidity profiles were used by averaging all points of each layer according to a certain threshold on sub-layer tracer normalized concentration (Tr). Black dots are for nearly pure undiluted parcels with Tr>0.99, green dashed line for nearly adiabatic (Tr>0.9), and red and blue curves include also slightly (Tr>0.7) and strongly diluted (Tr>0.1) parcels. It is shown that there are no pure adiabatic parcels above the inversion. Nevertheless, the use of slightly diluted parcels (with Tr>0.7) in our chosen reference method do not introduce large biases to LWC$_{ad}$ and AF accordingly.*

2. The AFs computed using the methods in section 2.3 are compared against the AF computed using the passive tracer. Is it a fair comparison to compare AFs calculated using two very different variables? The passive tracer is a conserved variable whereas LWC is not. Both these variables to some extent can be used for determining the adiabatic core, but once mixing occurs, then a one-to-one comparison may not be fair. Can the authors comment on that? If the authors agree, then what is the significance of the observations and conclusions from the current study?

Answer: We thank the reviewer for this comment. First, we note that in the absence of evaporation/re-condensation after a mixing event, AF can be considered as a conservative variable, similar to a passive scalar. Hence, even though the tracer and AF have their differences, they still share common properties (especially in volumes with relative humidity > 100%). For this reason, the tracer (which is an accurate measure of dilution) is used as a first order approximation for AF. Several assumptions were taken to obtain AF, which is based on a Lagrangian model (with its inherent assumption; some were mentioned by the reviewer earlier), from an Eulerian model outputs (as discussed above and in section 2.3). For this reason, we used the tracer to test the robustness of our AF calculations. This issue is discussed in lines 378-381: *"A sub-cloud layer's passive* *tracer (Tr), which is an accurate measure of mechanical mixing, was added to the simulations and used as a reference point. This model configuration enabled to better control AF and the complex processes that it represents, and to give a theoretical framework that allowed testing the accuracy of different approaches that are commonly used to calculate adiabatic fraction (AF)."*

We note that in most regions of the cloud the relative humidity is above 100%, which make the AF comparable to the tracer. In the next comment we discuss and suggest more complex reasons that act to deviate the two measures one from another.

Line 183 the text was revised to emphasize that the tracer is used only as a first order approximation: *"If there is a perfect undiluted adiabatic core, its AF value is equal to one, and it will coincide with the maximum normalized value of the tracer (Tr),thus Tr can be used as a first order approximation for AF."*

As the reviewer mentioned, in the core of the cloud the two measures should have a good agreement. In figure R1 below, we show the cross section of (AF-Tr) with the core ($Tr > 0.9$) marked by a black contour and magenta contour that marks the $Tr = 0.8$ line. One can see that the difference between the two is small in those regions.

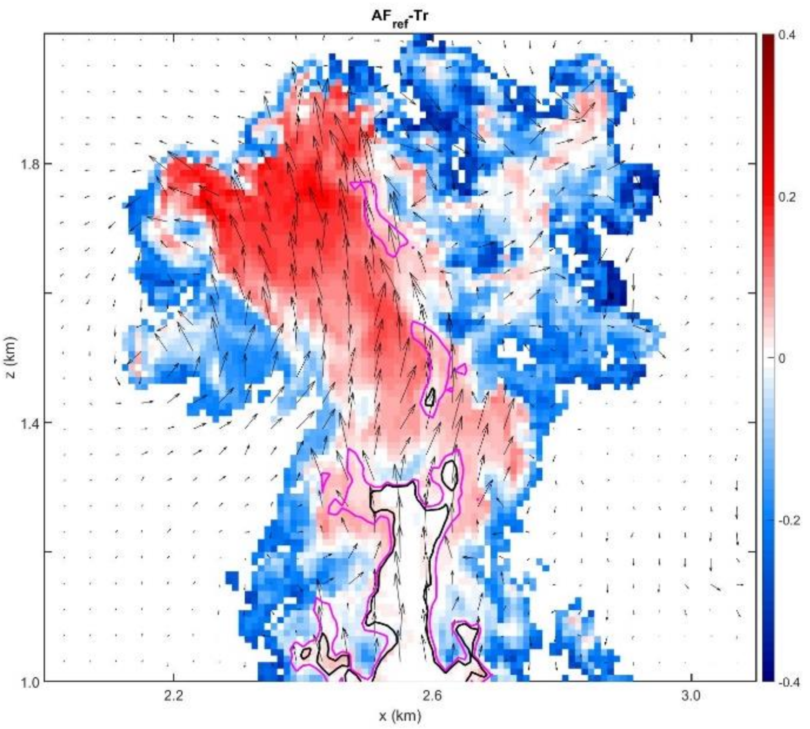

Figure. R1. Vertical cross section of AF_{ref}-Tr at the upper parts of the polluted cloud (N_a=500 cm^{-3}) at the time of maximal development (33 min.). Black contour marks the core where Tr>0.9 and magenta contour is for Tr=0.8.

3. In Figure 2(a), AFref>AF_scalar in the upper half of the cloud (the blue-colored region). The discussion related to this (lines 190-210) attributed it to the presence of toroidal vortices and enhanced updraft. The evidence provided to support this conclusion is not very concrete. The issues raised in the previous two points are relevant here. AFref>AF_scalar, this could also be due to a lower estimated LWC_ad. Since the calculations are based on the simulated cloud fields, the adiabatic LWC obtained using Eqs 5, 7 and 8 would be an underestimation compared to the actual LWCad as the cloud field is affected by entrainment. This is evident from the passive tracer field in Fig. 1(d). Thus, AFref> actual AF, and the actual AF would be very close to the AF estimated using the passive tracer.

Answer: We appreciate this comment that helped us clarify this issue in the revised manuscript. The issue about the credibility of our calculation of AF is addressed above in answer number 1. Figure A2 (presented in answer 1) and lines 211-223 explain that the bias of AF will not necessarily be underestimation, depending on the method that is used. Since we assume that our calculation of the reference method (AF_{ref}) gives a good estimation and is not prone to large biases due to the use of in-cloud profiles, we would turn to clarify our explanation of the regions where $Tr<AF_{ref}<1$. First, we note that if the reason was due to underestimation of the LWC_{ad} profiles, AF would be larger in the core as well (in regions of AF≈1), but there we see that AF≈Tr (see fig. 2a and 1d, and figure R1 above). Moreover, while the passive tracer is a simple conservable variable that flows according to the velocity fields, AF is based on a 1D parcel model. For this reason, unlike the tracer, it cannot consider horizontal motions and processes that occur away from the core (accompanied by mixing) and cause deviation from the core profiles. Such an example is given in the text and concerns a different condensation rate after a mixing event. If a parcel is highly diluted it remains with very small droplets concentration, then, if it continues to rise, local high supersaturation can occur. This local phenomenon cannot be considered in AF calculations because it is not represented in the estimated cloud core profiles. Thus, this parcel that experiences secondary nucleation (that is not assumed in the parcel model) and higher condensation rates than expected by the adiabatic parcel model. This will lead to local regions with $\frac{dLWC}{dz} > \frac{dLWC_{ad}}{dz}$ which means that AF ($\frac{LWC}{LWC_{ad(z)}}$) will unexpectedly increase with height. This hypothesized unique mechanism is tightly related to an old idea suggested by Baker et al., (1980) that explains super-adiabatic droplets [Baker, M.B., Corbin, R.G. and Latham, J., 1980. The influence of entrainment on the evolution of cloud droplet spectra: I. A model of inhomogeneous mixing. *Quarterly Journal of the Royal Meteorological Society*, 106(449), pp.581-598.]. Here we show that the toroidal vortex can continuously generate such conditions near the cloud's top. Figure R2 below shows a close-up on the upper part of the cloud, presenting the difference between the tracer and AF (**a**). In panel (**b)** we show the supersaturation field with its local high values that are found in ascending parcels just above the entrainment region of the toroidal vortex (on the left side of the cloud). The green contour aims to bound the "red regions" (where Tr > AF and the magenta contour marks regions of tracer=0.8 from the figure above (comment No. 2). Panel (**c**) shows the supersaturation values and points on correlations between high S values on the upper left side of the cloud and low droplets concentration. Finally, panel (**d**) presents AF_{ref} and show that the region bounded by the green contour contain intermediate values of ~0.8 that smoothly decrease to ~0.6. These values could be a consequence of increased AF from the toroidal vortex (as discussed above) or dissipated and diffused remnants of core fragments. Our results suggest the first explanation. This interesting role of the toroidal vortex is not the topic of this study and will be further studied in the future. In this paper it is only given as an example of regions in the cloud where the 1D adiabatic model can deviate from the tracer. For the sake of clarity of this manuscript, we re-wrote lines 221-240:

"The opposite is observed in higher levels, at slightly diluted regions, where Tr< AF_{ref}_<1. These regions represent a more complex difference between AF and Tr, which is also caused by condensation/evaporation. Tr can change only due to mechanical mixing and hence, is almost a one-directional process; once the parcel is diluted, it has low probability to restore its initial Tr concentration. This means that Tr has a memory of the mixing history, unlike AF that can be influenced by source and sink processes. A parcel can regain liquid water after a mixing event, if supersaturation is reached again at a later stage. Moreover, the parcels' condensation rate can be different from that predicted by the adiabatic parcel model, because its droplets size distribution have changed and the local profiles of supersaturation can be very different from the ones of the core. This means that a parcel in the margins of the cloud can be diluted, decreasing both Tr and LWC (AF), but later, if the parcel gains vertical velocity and supersaturation, it might condense water in a rate that is larger than in the core. This will compensate for the LWC loss (keeping Tr the same, while increasing AF; i.e. dLWC/dz>dLWCad/dz). The toroidal vortex seems to be a mechanism that drives such conditions. In Fig. 2a we show red regions of AF>Tr which are voxels of relatively strong updrafts and are part of the flow pattern of the toroidal vortex (for an elaborated discussion about the vortex see Zhao and Austin 2005). Using the velocity field, the regions of AF>Tr can be tracked back in time (back-trajectory) to their earlier location, where the toroidal vortex entrains environmental air. Those parcels that mix with entrained air are first diluted, and then flow upward driven by the flow in the toroidal vortex. These diluted parcels with low droplets concentration and high vertical velocity create high supersaturation values (higher than the values in the core for the same altitude). Hence, they condense water in a higher rate, which leads to local increase of AF with altitude. The phenomenon of rapid growth of droplets in an updraft following an entrainment event was suggested as a mechanism for rain initiation (Baker et al., 1980 and Yong et al.,2016). Correlations of the red regions (where AF>Tr) with strong updrafts (as part of the toroidal vortex), high supersaturation values and low droplets concentration were found for different time-steps and different cloud simulations."

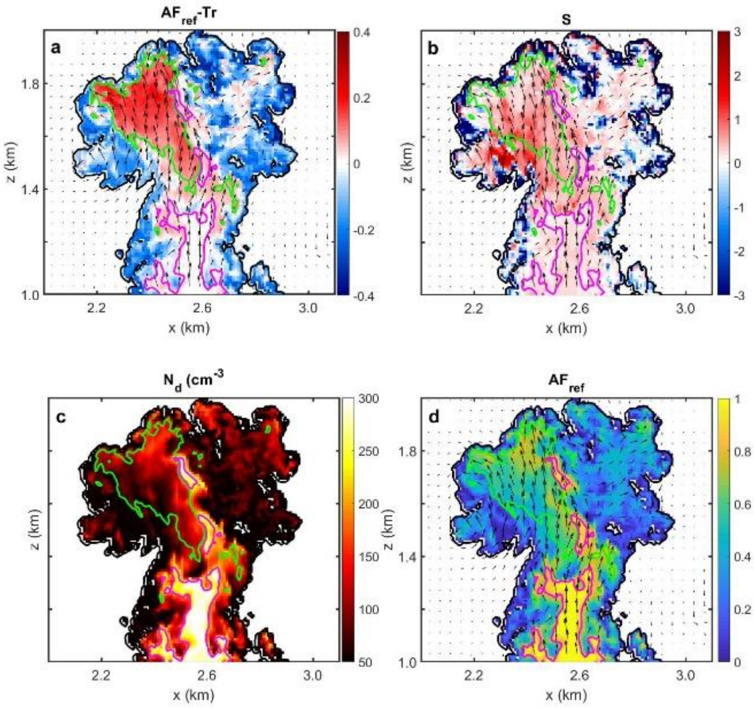

Figure R2. Cross sections of the upper part of the cloud. For the time of maximal development of the cloud (33 min.) with CCN concentration of 500 cm^{-3}. **(a)** The difference between the normalized concentration of the tracer (Tr) and AF. Green contour marks regions where AF>Tr and magenta contour marks the cloud core where Tr=0.8; **(b)** the supersaturation; **(c)** the droplets concentration N_d; **(d)** the absolute value of AF.

4. The authors say that one of the main objectives is to assess the methods used for computing the AF from the data generated from the field campaigns. Can the authors provide additional references to show which method is used for which field campaign and shed some light on how field data could be used for estimating AF? For e.g., what information is available during a field campaign and what calculations are conducted.

Answer: Thank you for the comment. In this manuscript we point out that there are many studies that use AF as a measure of mixing. Nevertheless, the details of its calculation from a given data set are usually missing (lines 123-125). We mention some studies that describe their approaches; like Gerber et al. (2008) who used eq. (7) and Schmeissner et al., (2015) who used eq. (8). Most studies calculated LWC_{ad} according to the saturation adjustment assumption as used in plotting a tephigram (Rogers and Yau, 1989; Khain and Pinsky, 2018). Accurate estimation of AF demands knowledge of the humidity and temperature profiles and of cloud base height. Those can be obtained by different ways in field campaigns. We revised the text to describe it shortly (see below). The present study aims to give an overview of the existing methods to calculate AF, and to analyze and emphasize the limitations of this basic and important variable. We hope that the results of this study can help any researcher (modeler or observer) to consider the options of how to use AF according to the limitation of this variable and the data that is used. This point is emphasized more clearly in the revised introduction and conclusions parts, and examples of current methods to acquired related data in the field are given.

Lines 67-74 in the introduction: *"Accurate estimation of AF demands knowledge of the humidity and temperature profiles and of cloud base height (as shown below in sect. 2.3), which are obtained in various ways in field measurements. While the humidity and temperature profiles can be obtained by radiosondes, aircraft profiling trajectories or remote sensing, the cloud base height can be estimated using calculation of the lifting condensation level (LCL), Lidar/ceilometer measurements or direct sampling according to visual identification from an aircraft. The supersaturation profile, which is a non-linear function of the humidity and temperature profiles, cannot be measured in the field at a suitable precision to the best of our knowledge. The different techniques by which the data was acquired will determine the resolution and precision, thus, affecting the best choice of method to calculate AF. "*

Lines 81-87 in the introduction: *"The simplicity and importance of AF make it applicable in many different data sets of both modeling and measurements. Since every observational data set will have different limitations (or models; e.g. varying schemes and resolutions), it is impossible for this paper to suggest one general solution to all (i.e. one algorithm of AF). This study uses a simple framework of a single cloud, while solving many of the interior complexities that affect AF, to suggest some tools for calculations of AF, and to present the limitations one might encounter while doing so."*

Lines 376-381 in the conclusions: *"This enables a better representation of mixing, and relaxes the dependency on sub-grid parameterization schemes. A sub-cloud layer's passive tracer (Tr), which is an accurate measure of mechanical mixing, was added to the simulations and used as a reference. This model configuration enabled to better control AF and the complex processes that it represents, and to give a theoretical framework that allowed testing the accuracy of different approaches that are commonly used to calculate adiabatic fraction (AF)."*

5. The standard measurement of entrainment/mixing is done via liquid water potential temp. Can't these conserved variables be used for calculating the AF from field measurements?

Answer: Variables that are conserved during expansion of air and phase changes such as total water mixing ratio and liquid water potential temperature (q_t or θ_l, respectably) are often used to estimate the mixing level of a cloud. Those variables are similar to some extent to the passive tracer that we used, i.e.

characterize dilution. These conservable variables have an advantage over our theoretical passive tracer because they can be measured in the field. At the same time, as we point out in lines 35-41, the limitation of such variables is that they exist also outside of the cloud and they change with height (they can also be different at the different sides of a cloud). This means that mixing with environmental air acts as another kind of source of q_t or θ_l. This is not the case for a sub-cloud passive tracer because we set it to zero above the cloud base (at the initiation stage). All of the arguments above mean that when using q_t or θ_l one has to assume some mixing properties. As an example, it is common to assume that a parcel experiences a onetime (immediate) discrete mixing event of cloudy parcel (with values calculated at cloud base) with the environment, and a linear combination of the volumes is assumed, such that:

$$\theta_l(x,y,z) = \theta_l^{base}\chi + \theta_l^{env}(z)(1-\chi)$$

Where χ is the cloud volume fraction, θ_l^{base} is the liquid water potential temperature at cloud base and $\theta_l^{env}(z)$ is for the environment at the level of observation. From this, one can obtain the mixing level as:

$$\chi = \frac{\theta_l(x,y,z) - \theta_l^{env}(z)}{\theta_l^{base} - \theta_l^{env}(z)}$$

Since mixing is a continuous process with relaxation time that can be significant and that a parcel can experience multiple events during its lifetime, these assumptions exert limitations on using natural conservable variables as measures of mixing. For this reason, we focus in our study on AF and its limitations. We believe that this is more applicable in field measurements. Moreover, we are interested largely in the microphysical variables like LWC, which experience evaporation and condensation. The mentioned lines were reformed to be clearer.

Lines 35-41: *"It is common to use conservative variables such as total water mixing ratio or equivalent potential temperature as they can be measured in the field. These variables' limitation is that they exist also outside of the cloud and above its base. This means that using these variables for estimation of the mixing level of cloudy volumes demands knowledge about their environmental profile and assumptions on the mixing processes. Sub-cloud tracer is preferable over these natural variables, as it is absent from the clouds' surroundings. However, such fictitious tracer do not exist in in-situ measurements and remote sensing and is only being used in numerical simulations, aiming for process-level understanding of mixing."*

Note, the LWC_{ad} and AF can be evaluated using conservative variables as total water mixing ratio (see Eq. 7) or conservation of moist static energy (Eq. 8). The problem is that the present methods show higher sensitivity to the choice of "adiabatic profiles" and that they do not allow to measure supersaturation. Accordingly, effects of saturation adjustment and other simplifications cannot be evaluated when using them.

6. One of the key difficulties in estimating the adiabatic LWC from the field data is related to knowing where the cloud base is located. If the location and the condition at the base are known, then plotting a moist adiabat is sufficient to know the properties of the adiabatic parcel (Rogers and Yau 1996, Bohren and Albrecht 2000). In the current study, there is no mention or discussion about this method. In my opinion, this would be the most fundamental method from the point of view of the field data, provided we know the height of the cloud base and its properties. Can the authors comment on this? There might still be issues related to supersaturation that needs to be investigated.

Answer: We thank the reviewer for the comment that enabled us to clarify the text. The method described by Rogers and Yau is the first method that is tested and discussed in section 3.2.1 (Linear LWC_{ad}). This method assumes that the moist lapse rate of a parcel is constant with height, hence we can deduce LWC_{ad} by knowing the temperature and humidity at cloud base. The manuscript is referring to the short paper of Pontikis (1996) that derived LWC_{ad} (see Eq. 8 in this paper), using the definition of Roger and Yau to the moist adiabatic lapse rate (Eq. 7 in Pontikis 1996 is similar to Eq. 3.16 in Rogers and Yau). We note that the final solution given by Pontikis is similar to our solution of constant ratio of A_1/A_2 (see definitions of the parameters in eq. 2a,2b); the difference is with the used units (mixing ratio vs. density), hence in a factor of the density of dry air (ρ_a). We added a reference to Roger and Yau in the text and noted that our solution is identical to the solution of Pontikis.

Line 278: *"This implies that A_1/A_2 can be used as a constant, based on the known values at the cloud base. Note that the derivation of AF using Rogers and Yau (1996) leads to the equation of A_1/A_2 at cloud base."*

7. Line 355: "condensation that occurs after a mixing event can delete records of earlier evaporation/dilution events" – I do not think this statement is supported by the data or the discussion presented in this work. The LWC a parcel attains at a given height is an integrated effect of past entrainment/mixing/evaporation/condensation events. Without knowledge of this history, the final LWC cannot be computed. So, I do not understand the above-quoted statement from the authors. If the authors do not agree, they need to provide strong evidence to support this statement.

Answer: This comment is related to comment number 3. A deeper discussion about this point is given in lines 195-200 in the original manuscript and in our answer above.

8. Finally, the title of the paper is a bit too general. The objective of this study appears to be to assess various techniques used for estimating the adiabatic LWC and does not shed much light on the adiabatic core/mixing processes/adiabatic fraction in cumulus clouds. The authors could come up with a more specific title that reflects the scope of the work.

Answer: We thank the reviewer for this comment, the title was changed to describe the paper more clearly: "*Revisiting Adiabatic Fraction Estimations in Cumulus Clouds: High-Resolution Simulations with Passive Tracer*"

Minor Comments:

1. The abstract should contain the key results/conclusions of this study.

Answer: The main results were added to the abstract:

" Comparison of three different methods to derive AF to the passive tracer show that one method is much more robust than the others. Moreover, this methods' equation's structure also allows to isolate different assumptions that are often practiced when calculating AF such as: vertical profiles, cloud base height, and the linearity of AF with height. The use of a detailed spectral bin microphysics scheme allows accurate description of the supersaturation field and demonstrates that the accuracy of the saturation adjustment assumption depends on aerosol concentration, leading to an underestimation of AF in pristine environments. "

2. Line 21: Diffusion efficiency of what?

Answer: The line was revised for clarity (Line 23): *"As an example, high aerosol loading conditions increase the number of droplets and their surface area to volume ratio, which increases the rates of condensation or evaporation"*

3. Line31: conserved and not “conservative”.

Answer: Corrected, thank you.

4. Lines 36-38: Can the authors give examples of scenarios when radiation and sedimentation effects can be neglected.

Answer: We appreciate this comment. Sedimentation can be neglected when the liquid water droplets total mass is dominated by droplets smaller than ~30 µm, this holds mostly for clouds with high droplets concentration and in the lower parts of growing clouds. The averaged droplet radius of typical marine boundary layer clouds in the trades does not exceed 15 µm, i.e. fall velocity is less than 2-3 cm s^{-1}. It means that the vertical shift of droplets with respect to ascending air does not exceed ~10 m (which is the vertical resolution used here) during the growing stage, i.e. negligibly small.

Since clouds strongly reflect the solar radiation, absorption can be neglected; radiative cooling might be significant near the top of clouds below dry atmosphere. An example for such scenario is the cloud top of stratocumulus clouds. In our case, we made sure that our analysis is free of large sedimentation rate (see lines 321-326) and we did not implemented radiation transfer model in the simulation. This is now specifically written in line 175-178:

“In this work, we analyze the growth and mature stages of shallow cumulus clouds, before obtaining considerable sedimentation flux. Shallow Cu life time in general is short, hence the radiative heating by the weak absorption of solar radiation or cooling by thermal radiation emittance can be neglected. Therefore,

we did not calculate radiation transfer during the simulation. Neglecting sedimentation and radiation allows to use AF as a measure of mixing."

5. Before Eq 8.: the definition of moist static energy is not correct. h = Lvqv+CpT+gz. Some additional clarification/steps are required in deriving Eq. 8.

Answer: We thank the reviewer for this comment. The typo was corrected and the assumption of conservation of water mass was added to explain the translation of q_v to q_l:

"The third approach is to use the conservation of moist static energy (h), where h = $L_w q_v$ + cpT + gz. Differentiating h with respect to z, conserving it with height (dh/dz = 0), assuming water mass conservation (i.e., $dq_v = -dq_l$) and multiplying by ρd gives (Schmeissner et al., 2015):"