<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) and changes are marked in yellow in the text of the revised manuscript.

Reviewer 2:

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

General comments:

This manuscript compares various method in calculating adiabatic fraction in cumulus clouds, which is an import parameter in quantifying the mixing level. The authors compared three ways in calculating the adiabatic LWC and their impacts on the AF. Besides, the authors examine the assumptions made in previous studies about the calculation of AF. This manuscript is clear about their method but lacks more explanations in the application of this study. I recommend a revision to emphasize the significance of this study more in either introduction or the discussion paragraph. Other specific comments and the minor corrections are below.

Answer: We thank the reviewer for this comment. The introduction and conclusion sections were revised to highlight the significance of the study and to state more clearly what practical actions can be deduced from the study when calculating AF. Please see below detailed answers to all the comments.

Specific comments:

1) This study mentioned that it aims at identifying the errors from the assumption in calculation of AF in observations, but the manuscript only shows the results from an idealized model study. Can the author provide more clear linkage that how the results can improve the analysis of observation data?

Answer: In this manuscript we point out that there are many studies that use AF as a measure of mixing. Nevertheless, because this variable is so basic, the details of its calculation from a given data set are usually missing (lines 123-125). Several in-situ measurements present values of AF in Cu, usually by assuming that it is linear with height and saturation adjustment. Here we offer a theoretical study that aims to give an overview of the existing methods used to calculate AF, and to analyze and emphasize each method's limitations, together with the general limitations of AF. Since the number of studies that use AF is large and includes both modeling and measurements, whom each one has different data sets; we are unable to address all studies and give a unique solution to the problem. 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 his particular data. As an example, we discuss the strong limitation of using AF in deep convective clouds or point out to biases that saturation adjustments can cause under different aerosols conditions. In order to provide a linkage to field measurements we added sentences that describe the data that is acquired in the field. These points is now more emphasized in the introduction and conclusions parts.

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 81-85: *"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."*

2) The reference AF is based on Equation 6 without considering the supersaturation (Line 166). The Section 3.2 shows that not considering supersaturation leads to errors especially in the lower cloud region of cleaner scenario. I think it better to use the full equation (Equation 5) to calculate the LWC_ref since it has less assumption.

Answer: We thank the reviewer for this comment. The choice of AF_{ref} is indeed not the choice of the most accurate method, but the choice of the method that can be compared with all other methods. By using AF_{ref} (eq. 6) we can isolate the effect of each assumption or term in the equation. For example, the comparison in fig. 3b only takes A_1/A_2 to be constant with height and in fig. 3d only adds the second (supersaturation) term. By comparing the full equation (eq. 5) to the linear assumption (which cannot include profile of supersaturation) we will be mixing biases of both linear and saturation adjustments assumptions.

A line was added to make this point clear (Line 274): *"Each approach will be compared with the reference approach (AF_{ref}; Eq. 6). This method is not the most accurate one (method AF_s using Eq. 5 is), but since it is the base for all other examined assumptions, using it allows to isolate and examine each of the assumptions separately.*

3) What are the recommendations for the calculation of AF in the future studies?

Answer: We appreciate this direct comment. A short list of the recommendations for all studies that use AF was added to the end of the summary and conclusions section (lines 414-432):

1) Calculations of AF will be most robust when using eq. 5 (or eq. 6 in polluted conditions).
2) When using AF for studies of aerosol-clouds interactions by comparing different parameters conditioned by AF, one cannot make the saturation

adjustment assumption as it underestimates AF in pristine conditions and can bias the results.

3) AF is most sensitive to the definition of cloud base height. Thus, it is important to make sure that the chosen value well represents the investigated cloud or clouds, at the altitude in which most parcels started to condense water.
4) AF in deep convective clouds is prawn to many large errors, and the uncertainty of the calculations is hard to asses (see line 384-391).
   Mainly:
   a) AF is based on a quasi-hydrostatic equation, which is valid for updrafts smaller than 10 m/s.
   b) Supersaturation in clouds with strong updrafts can increase, leading to underestimations of AF if the S term is neglected.
   c) Sedimentation of particles from higher levels of deep clouds can increase LWC in their lower levels and lead to an overestimation of AF.
   d) The rate of change in LWC_{ad} is dominated by the parameter A_2, which changes as water vapor is depleted in clouds, meaning that LWC_{ad} ceases to be linear. The large differences expected in deep clouds between the in-cloud and environmental profiles suggest that the latter is prone to large biases when used to predict AF.

4) This study has removed large-scale wind. How are the results influenced by a mean wind?

Answer: Adding a mean wind (and shear) can increase entrainment and mixing and affect the cloud evolution and the cloud size. However, the methods of LWC_{ad} (z) calculation will not change. For simplicity we chose to simulate an environment with no large-scale wind. This is now pointed out in lines 83-87:

" 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. External complexities such as advection, wind shear, surface fluxes and variations of aerosols will add complexity to the cloud system, but are not expected to change the nature of AF (only its resulted distribution)."

Minor corrections:

5) Figure 2: it is better to show the differences by the AF-Tr, which is more straightforward for the readers to tell overestimation or underestimation.

Answer: Thank you for the comment the figure was changed.

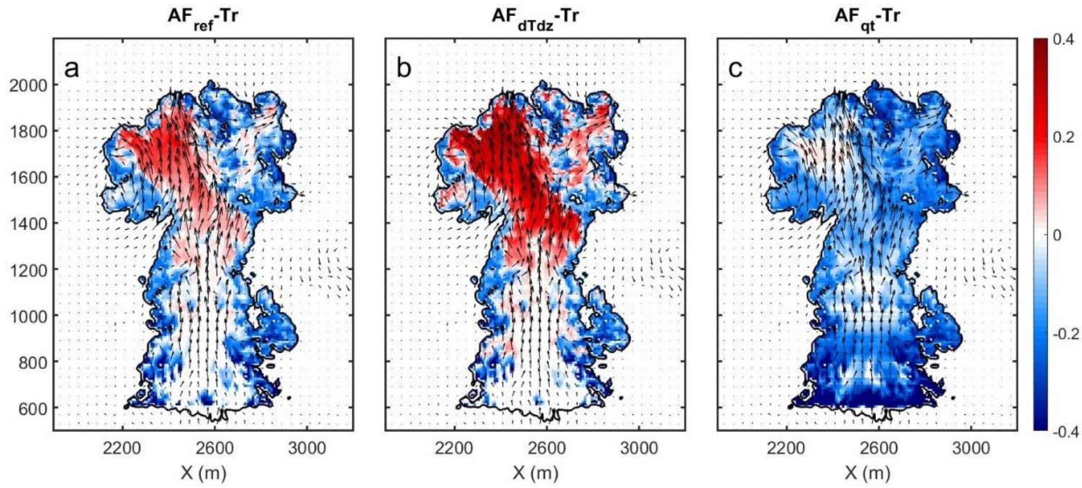

Figure 2. Cross-sections of the differences between the various AF methods and the tracer. Vertical cross-sections for the differences between methods using approximated profiles (Fig1e-g) and the tracer (Fig. 1d). (a) Difference between AF_{ref} and Tr (Fig. 1e minus Fig. 1d). (b) Same as a, for AF_{dtdz}. (c) Same as a, for AF_{qt}.

6) Figure 6 and Figure 7: it is better to use red-white-blue colors to show the differences (similar color scheme as Figure 3b-3f)

Answer: We thank the reviewer for the suggestion. Since each panel has a bias of one direction, we prefer to use a colormap that allows a higher resolution in colors and not only different shades of blue or red.

7) Line 224: ql should have the l as subscript?

Answer: Thank you, the error was fixed.