Replay to Reviewer 1

“Revisiting Adiabatic Fraction Estimations in Cumulus Clouds: High-Resolution Simulations with Passive Tracer” by Eytan et al. 2021

I thank the authors for submitting such a detailed response. Some additional clarification may be required about comment 6.

If the cloud base thermodynamic properties are known then one can obtain the adiabatic parcel temperature and water vapor (assuming saturation adjustment, i.e., thermodynamic equilibrium) at any height. So, why is there a need to assume A1 and A2 to be constant? Even a constant assumption seems very close to AFref (Fig 3b). So if the adiabatic variation in temp. and water vapor is accounted for how will that fair against AFref? All three methods can be re-evaluated using the moist adiabatic parcel temp and water vapor data. My guess is that all three methods will give similar results. It will be nice to see how they compare against AFref?

> Once this comment is addressed satisfactorily, I recommend the acceptance of this manuscript.

Answer: We thank the reviewer for this comment and we clarify the regarded points below.

The coupling between the condensate mass in an adiabatic parcel (LWC_{ad}) and the temperature profile requires knowledge about one of them for calculating the other. Hence, it does not allow accurate estimation of the LWC_{ad} based only on knowledge of cloud-base temperature and humidity. When taking analytical methods to estimate LWC_{ad} while using only cloud-base properties, some additional assumptions have to be made (e.g., constant moist lapse rate and a constant ratio of A_1/A_2). This will be explained and demonstrated by the equations below.

In this work we considered only analytical approaches (rather than numerical solutions), since they are more abundant in the literature and because they are simpler to use and are cheaper computationally. Below we derive the analytical solutions according to the book by Rogers and Yau (1996), (which was mentioned by the reviewer in comment no. 6 in the former review), and show that those solutions are identical to some of the methods that were presented and tested in the manuscript.

The change in liquid water mixing ratio (q_{ad}) with altitude (which is proportional to LWC_{ad}) can be deduced from Rogers and Yau 1996 (page 32, Eq. 3.15). In that equation, one can see that the change in q_{ad} is indeed a function of the temperature profile, as stated above.

Isolating the vertical gradient of water vapor mixing ratio (q_v) in the equation, and assuming mass conservation (the decrease in water vapor is due to condensation and increase in liquid water) gives:

$$(1) \qquad \frac{-dq_v}{dz} = \frac{dq_{ad}}{dz} = \frac{c_p}{L}\left(\frac{dT}{dz} - \frac{TR_d}{c_p p}\frac{dp}{dz}\right)$$

where T is the temperature, c_p is the heat capacity of air, p is pressure, L is latent heat and R_d is the gas constant of dry air.

Assuming hydrostatic balance and an ideal gas gives:

$$\frac{dq_{ad}}{dz} = \frac{c_p}{L}\left(\frac{dT}{dz} + \frac{g}{c_p}\right) \tag{2}$$

where g is the acceleration of gravity.

This solution (Eq. 2 here) is identical to Eq. 8 in the manuscript (method AF_{dTdz}; derived from the moist static energy) that is tested and presented in the paper. Note that the difference in a factor of dry air density comes from the usage of different units (mixing ratio in the book and density in our manuscript). As the reviewer mentioned, this method is comparable to the main (reference; AF_{ref}) method in the manuscript, but only in ideal conditions; with accurate information on the cloud's core profiles (see Fig. A2 and Fig. 1).

In the manuscript, we tested this method by taking the temperature profile (dT/dz) of the cloud's core. Another approach is to approximate the temperature profile by considering the saturation adjustment assumption and using the Clausius–Clapeyron equation (i.e. referred by the reviewer as the moist adiabat). This is given in Rogers and Yau 1996 by Eq. 3.16:

$$\frac{dT}{dz} = -\Gamma_d \frac{1+\frac{Lq_{vs}}{R_d T}}{1+\frac{L^2 q_{vs}}{R_v c_p T^2}} \tag{3}$$

where Γ_d is the dry adiabatic lapse rate and is close to g/c_p.

Substituting Eq. (3) into Eq. (2) yields a solution that is identical to Eq. 6 in the manuscript which is the reference method (AF_{ref}).

If one wishes to simplify LWC_{ad} calculations and use only the cloud-base properties, it is possible to assume (under some conditions, as shown in the manuscript) a constant moist lapse rate (i.e. using the humidity and temperature values at cloud base). This method (AF_{linear}) was applied in the paper by assuming a constant value of the ratio of A_1 and A_2 above cloud base. It is identical to solving Eq. 3 from above by using the cloud base temperature and water vapor mixing ratio.

Finally, we emphasize again an important point in the manuscript: the derivation and equation that we chose to use in the manuscript (given below as Eq. 4) gives the full equation of LWC_{ad} without the saturation adjustment assumption. This allows to consider the bias of this almost inherent assumption in LWC_{ad} calculations under different conditions.

$$LWC_{ad}(z) = \int_0^z \frac{A_1(z')}{A_2(z')}dz' - \int_0^z \frac{1}{A_2(z')}\frac{dS}{dz'}dz' \tag{4}$$