Response to Reviewer 1

We thank the reviewer for the insightful comments and for noting some important corrections. As detailed in the following, we have revised the paper in accordance with each point. Detailed changes are indicated in the highlighted manuscript uploaded with this response. Here, reviewer comments are in blue text and our responses are in black text.

This paper investigates if cloud parcels that go through a mixing event can produce larger droplets than undisturbed parcels (this is called super-adiabatic growth by the authors). Mixed parcels contain less water and fewer droplets than undisturbed parcels, and therefore droplets there grow faster after a mixing event, although starting from a smaller radius. From thermodynamical considerations, the authors show that super-adiabatic growth is expected for a pristine environment when mixed parcels rise to a given height. This height mostly depends on the thermodynamical properties of the cloud and of the environment, and it is independent of the updraft velocity and of the mixing fraction. This result is tested with a parcel model for different updrafts velocities, different polluted environments and for a polydisperse droplet population.

It has been argued in the past that super-adiabatic droplet growth can help to explain rain formation in warm clouds. The authors are able to quantify this effect in idealized conditions, and I think that their results can be used to estimate the relevance of the mechanism in future studies. For these reasons, I think that the work can be a worthy publication for ACP if the authors answer the next questions.

1) One of the inherent assumptions for the parcel model and for the thermodynamical calculations is that the parcel only mixes once with the cloud-free environment, which means that it never mixes with cloudy air. I would like that the authors discuss this assumption more in detail. Clouds are turbulent and continuously mix (see for example Margaritz et al. 2014), which homogenizes the droplet number concentration. In the example from Figure 1, the parcel has to rise for ~3000 seconds without mixing with other cloud parcels in order to become super adiabatic. It seems unlikely for me to find such a parcel in a real cloud.

This comment is of course correct, and the reviewer is right to request further justification of our idealized approach. As stated in the reviewer comment, a cloud parcel continuously mixes with both cloudy air and the environment air throughout its trajectory. Lagrangian results such as those of Magaritz et al. 2014 and others (e.g., several already cited in the paper, including Cooper et al. 2013, de Lozar and Muessle 2016, Lasher-Trapp et al. 2005, Magaritz et al. 2015, and Naumann and Seifert 2015) have demonstrated some effects of internal mixing, especially due to sedimentation when drizzle is present, and that dilution events often take place repeatedly during parcel ascent. The results presented here do not consider those more realistic conditions, but instead are purposefully designed so as to avoid the complexity of a real cloud and look at the idealized response to a single dilution event. Our motivating philosophy is that if we can understand the ‘impulse response’ from one mixing event with analytical results, then that understanding can be extended to more complex scenarios. The main purpose of this paper is therefore to study how the cloud microphysical properties in a diluted parcel change when it rises adiabatically after the mixing event, and indeed the derived results are shown to be consistent with a more detailed (yet still idealized) parcel model. The analytical results might be useful to calculate the entrainment rate profile for the real cloud, similar to Lu et al. (2012), for example. We have added more discussion in the introduction to motivate our idealized approach and how it can be placed in context with more complex, real cloud turbulence. As part of that discussion we include a citation to Magaritz et al. (2014), as well as to several other papers that draw attention to the microphysical effects of internal and external mixing (Korolev et al. 2013, Wang et al. 2009).

2) It would be interesting to know the authors conclusions about the role of super adiabatic droplets for large droplets production and rain formation, from the results presented in the paper. Do they think that the mechanism is relevant for all warm clouds or only in a few particular cases (very wet and very clean environment)? Do they think that the mechanism is relevant for stratocumulus (which are usually thin (~300 m), with a dry capping free atmosphere and with mixing only on the top)? Can they estimate how does the droplet size distribution broaden due to this mechanism (is it sufficient for rain formation)?

Our results show that a mixed/diluted parcel is more likely to reach the superadiabatic growth region if the environmental air is wet and clean. This mechanism might be relevant not only for cumulus, but also for stratocumulus cloud. For example, as mentioned by reviewer 2, Wang et al. (2009) describe a circulation mixing hypothesis to explain microphysical properties in stratocumulus clouds. The circulation mixing hypothesis is similar in spirit to the assumption in our study, except it is conceptually dependent on multiple dilution events and therefore somewhat more qualitative. The circulation hypothesis of Korolev et al. (2013) also has some similarities and is able to produce large droplets that, by our definition would be considered superadiabatic. Our results focus on the possibility of enhanced growth of cloud droplets when they enter the superadiabatic growth region. When those enhanced-growth cloud droplets are mixed with other cloud parcels, the size distribution will be broadened, and while we mentioned this possibility, we have not quantified the broadening effect. This is definitely a key topic that needs to be the focus of future research. We have added some discussion of these points in the introduction and discussion sections.

Technical corrections:

1) Line 120. Equation (4) can be directly obtained from Eq. (1) in the quasi-stationary limit. No need to refer to Eqs. (2) and (3).

Thanks for the reviewer’s comment. Yes Equation 4 can be obtained from Equation 1 and we have reordered the equations to make this clear. Because quasi-stationary supersaturation (former Equation 2) is used to explain the enhanced growth of cloud droplet in the mixing parcel, we still keep it.

2) Line 135. There is a prefactor missing in the definition of the liquid potential temperature, which accounts for the pressure dependence. With the current definition, liquid potential temperature is only conserved for adiabatic and isobaric processes. Also, I do not see why \epsilon appears in the definition (it does not appear in Gerber et al. 2008).

Thanks for the reviewer's comment. Yes, we didn't consider the pressure effect on liquid potential temperature. This assumption works if the cloud is not thick. We add more discussion in the text. Because the unit of lw is J/mol (not J/kg) and the unit of cp is J/mol/K (not J/kg/K) (see Appendix), epsilon is a constant to change the unit of lw to J/kg, and change the unit of cp to J/kg/K. Our unit is not as usual as previous paper, but it's consistent in our paper and consistent with that in Lamb and Verlinde's textbook. There were no errors and our results were correct. Since both reviewers were confused by the notation, however, we have changed to the mass-based units in the text since this is the most common terminology.

3) Line 141. Equation number missing.

We've added the equation number in Line 141.

4) Line 151. I would not discuss the state im (after mixing but before phase changes). It is not very useful for the discussion, and it adds more symbols.

We've removed $q_{v,im}$ and T_{im} in the text.

5) Line 156 and 192. Equation 2.1 does not exist.

Equation 2.1 should be Equation 6 (former Equation 7). We've changed it in the text.

6) Line 246. Explain better why ql,fm /ql,f = \chi is the condition for the critical height. Remind the condition of completely clean environment.

This condition only works for the cloud parcel with monodisperse cloud droplet when mixing with clean environment. For a clean environment and homogeneous mixing, it's true that $n_{d,fm}/n_{d,f}$ = \chi as long as droplets in the mixing parcel don't totally evaporate. Here n_d means the cloud droplet number concentration. For monodisperse cloud droplet, if ql,fm/ql,f also equals to \chi, it means that the droplet sizes in both mixing and original parcels are the same. Because ql=4/3pi rhol r^3 Nd. More explanation is added to explain the condition for the critical height.

7) Line 316. Provide the number of CCN in the polluted environment.

For the polluted case, the dry aerosol distribution in the environment is the same as that below the cloud. The total number concentration of aerosol is 50 #/g. The number of cloud droplet can be seen in the new Figures in the supplementary material.

Finally, we have slightly edited the abstract for concision and clarity in accordance with the implemented changes.