Comments on "Theoretical study of mixing in liquid clouds – Part 1: Classical concept"

The main contribution of this paper apparently is to demonstrate the relationship between different moments of the size distribution for the limits of homogeneous and extreme inhomogeneous mixing. Analytical results are compared with the results from a parcel model. The conceptual picture of inhomogeneous and homogeneous mixing is well illustrated in Figure 1 and the central analytical expression is validated in Figure 2. Figures 3-8 then show the response of different moments of the cloud droplet size distribution to idealized mixing processes. Figures 9-11 describe a conceptual model of a cascade of mixing events between a dry parcel and the cloud, which is a step toward making comparisons between the theory and observations within an evolving cloud environment. Section 4 and Figures 12-15 provide a brief analysis of observational data in the context of the conceptual models developed in the previous sections. The analysis is useful in attempting to connect the concepts and idealized models to the more complex situation observed in real clouds. The paper ends with a discussion of characteristic time scales, which seems somewhat disconnected. It is not clear how this integrates with the previous sections, and perhaps it should be either moved closer to the introduction or separated as an appendix. If kept in this location, its logical flow with the rest of the paper needs to be improved. Overall, my sense is that the expanded view to consider different moments of the size distribution is a valuable contribution, especially for the experimental cloud physics community, but perhaps also for applications to radiative transfer, remote sensing, etc. I am not aware of other papers where different moments are considered thoroughly as here, so this seems to be original.

General criticisms:

1. The application to size distribution moments is original, as far as I am aware (Jeffery gave a brief discussion of how the second moment is affected by mixing, but the treatment here is much more thorough and covers all typical moments). But much of the conceptual model is written more like a textbook. Maybe this is nice for readers new to the field, but the authors take a risk in expanding the length of the paper, especially when combined with the other two parts. Much more important, and definitely missing from the introduction as it currently stands, is some kind of overview of how the three part series fits together. What are the different levels of complexity treated? Why are two specialized papers on homogeneous and inhomogeneous mixing needed if part 1 already treats both cases? Now that I have read all three parts I have an idea, but this needs to be clear from the outset. It is especially important to motivate why part 1 should be connected at all. Currently it is disconnected in its approach, in its use of observational data, and even in its notation. The use of observational data is nice, but it is somewhat confusing given the title "theoretical study…" The

notation is a major problem that needs to be corrected… the physics is difficult enough by itself, without having to translate symbols from one paper to the next.

2. After a long preliminary discussion, the most important paragraph in the introduction is on page 30214 starting at Line 26: "Besides the effect on N and r the type of mixing is anticipated to manifest itself in relationships between other moments of the droplet size distribution…" It should be further explained in that paragraph why it is valuable to analyze different moments. Are they expected to be more insightful than the traditional mixing diagram methodology; is it making applications of mixing to other fields clearer; etc?
3. In Fig. 9 and after, a multiple-step mixing process is envisioned. The approach is to consider mixing between a cloud and the dry environment, and then to consider subsequent mixing events between that parcel and the cloud again. Why did the authors choose to take this view instead of considering a cloud parcel progressively mixed with clear air? Some motivation for that choice is needed and some discussion of how the results would be expected to differ. For example, if one were to focus on the dry air first, dots should be concentrated at lower end in Figure 10.
4. There are many mistakes in the paper, including errors in the equations, at least according to the derivations as I am able to follow them. Again, the physics is difficult enough by itself, without having to make corrections. Please thoroughly check all results and the typesetting.

Specific comments

1. Eq. 1, page 30218: As monodisperse cloud droplets are used in this part of the study, the droplet size distribution f(r) will confuse people. Especially Equations 2 and 3 only work for monodisperse droplets theoretically. Please explain and be consistent.
2. Eq. 5: prefactor should be ($c_p R_v T_{mo}^2/L^2$)? T_{mo} not T2?
3. It is difficult to connect Eq. 8 to Eq. 5. How do you prove Eq. 5 is (1-u)Eq.8, when $T_1=T_2=T_{mo}$?
4. Line 21, page 30218: q is liquid water mixing ratio (g/kg), not liquid water content (g/m^3).
5. Line 6, page 30220: The neglect of latent heat is a strong assumption that removes possible important factors such as negative buoyancy production. It is valid in the range specified by the authors, but the limitation should be discussed. Does it restrict the results to certain environments or cloud types (e.g., shallow convection)?
6. Line 7, page 30220: "comparisons of with numerical…" needs to be corrected.
7. Line 13, page 30220: missing space between "on" and "delta_q"

8. Line 17, page 30220: the volume change due to temperature change should not affect liquid water mixing ratio, because it's connected to mass not volume as mentioned in point 4.
9. Eq. 8: prefactor should be ($c_pR_vT_2^2/L^2$)?
10. Eq. 13: left side should be r_3^3/r_{30}^3
11. Eq. 14b: I think the right side should be $(q/q_0)^{2/3}$(q+delta_q*/q_0+delta_q*)$^{1/3}$
12. Eq. 16: I believe the exponent should be -1/3, and inside the parentheses should be N_0/N.
13. Eq. 20: right side should be $q^{2/3}$(q+delta_q)$^{1/3}$/q_0
14. Fig. 3: it looks like panels a and b are mixed up. Also the caption refers to liquid water mixing ratio but the axis label states LWC; needs to be consistent.
15. Figs. 3 and 4: should use same format for S through the whole paper (e.g. 20% as in Fig.4 or 0.2 as in Fig. 3)
16. Lines 12-15, page 30224: Lots of problems here. Where are the black stars in Fig. 4? Do you mean the stars in panels a and b of Figure 3, or should there be stars in Figure 4 too? And by the way, the stars in Figure 3 are very difficult to see… I had to search for them. And again, regarding text on line 14, the question of LWC versus q comes up. Finally, on line 15 it is not obvious to be that the statement is for Figs. 3 and 4. Do you mean to include Fig. 2 also?
17. Line 25, page 30226: q_0 is not liquid water content.
18. Line 9 page 30227: Fig.17 should be Fig. B1?
19. Fig. 7: why changes from r_0=10um (Fig. 4,5,6) to r_0=5 um. And also changes the S from 50% to 90%?
20. Fig. 8: My understanding is that homogeneous and inhomogeneous mixing coincide with each other for S_{mo}>1? It's hard to see this phenomenon in Fig. 8 (might use different colors or symbols?) also line 5 page 30228: unclear, should be "exceed those for inhomogeneous mixing for delta_T=0 and delta_T=5…?"
21. Line 5, page 30228: in Fig. 8, Delta_T is negative, here it's positive.
22. Line16, page 30228: could you explain why "the effect.. is more pronounced when T_1>T_2 compared with T_1<T_2."
23. Line 27, page 30229: "becomes denser towards the top right corner" Is it because the mixed volume is mixed with cloud volume, not environmental volume?
24. Fig. 11: why use r_0=5 um, not 10 um. It's better to use the same radius through the paper, except you want to do the sensitivity test.
25. Line 13, page 30231: missing space between "q" and "beta"
26. Line 14, page 30231: define Sc, Ac, Cu, Cb
27. Line 1, page 30232: missing space between "N" and "q"
28. Fig. 13: caption T=-12 not -120

29. Line 13, page 30233: how does sample averaging affect homogeneous versus inhomogeneous mixing?
30. Fig. 14a: y axis unit (g/m^3) not (km^{-1})
31. Fig. 14: what's the dash line in a,b,d
32. Line 9, page 30237: Da>>1 is for inhomogeneous mixing, while Da<<1 is for homogeneous.
33. Line14, page 30237: Andrejczuk is misspelled both here and in the reference list.
34. Lines
35. Lines17-22, page 30238: lambda_ev, lambda_v, and lambda_DeltaV need to be defined, and the assumptions in calculating them clarified (e.g., evaporating distance assumes droplet always falling at terminal speed corresponding to time-dependent radius?).
36. Line 6, page 30240: S_2 approximate 1 not 0?
37. Line 6, page 30240: missing space between "concentration" and "n_{ev}"
38. Fig. 16: define A and B in the text or caption
39. Line 13, page 30240: missing space
40. Line 15, page 30240: missing space
41. Eq. B4: left side should be T_{mo} not T_m
42. Eq. B8: There seem to be mistakes here. I believe the prefactor should be ($c_pR_vT_{mo}^2/L^2$) and T_{mo} not T_2?
43. Line 14, page 30244: "is hold" should be "holds"?
44. Line 15, page 30244: Figure B1 is Figure 17.
45. Table A1: there are two \tao_ev

Closing comment: overall, I would say that 45 detailed corrections is too many; I will not make such detailed formatting comments on the next two parts and request that the authors take care to check these things independently.