Response to Referee #2

Title:
Comprehensive Quantification of Height Dependence of Entrainment-Mixing between Stratiform Cloud Top and Environment

Author:
Sinan Gao, Chunsong Lu, Yangang Liu, Seong Soo Yum, Jiashan Zhu, Lei Zhu, Neel Desai, Yongfeng Ma

Summary:
This study proposes a new measure for the homogeneous mixing degree which is independent of any adiabatic values. This measure was developed using observational data of marine stratiform clouds measured from aircraft during the campaign of Physics of Stratocumulus Top (POST) data. It is proposed that new method of mixing degree can be alternative method to quantify entrainment-mixing mechanisms by overcoming difficulties of determining adiabatic microphysical properties needed in the traditional approaches.

Comments:
The paper is written well and provide another way to quantify the degree of mixing. It is worth to publish in ACP with minor corrections given below.

Reply: Thank you very much for appreciating the importance of our work!

1. Regarding observation:
   (i) Cloud droplet size distribution is measured by CAS probe however, the particle size range in CAS is not mentioned such 0.5-50 μm.
   (ii) CAS has disadvantage of large size bin width (about 10 μm) for above 20 μm particle diameter, therefore, does not give accurate size resolution. On the other hand, CDP or FSSP probe has better size resolution. Why did the authors choose CAS probe for this study?

   Reply:
   (i) We have added the particle size range in CAS in Lines 88-90: "The Cloud and Aerosol Spectrometer (CAS) probe measured size distributions in the radius range of 0.29 - 25.5 μm at the frequency of 10 Hz. The data in the radius range of 1.0 - 25.5 μm are used to calculate microphysical properties, i.e., number concentration (n_c), liquid water content (LWC_c) and volume mean radius (r_{vc})."
   (ii) Yes, we agree with the reviewer that the CAS probe has disadvantage of large size bin width (about 10 μm) for above 20 μm particle diameter. However, only the data from the CAS probe are available in this field campaign. Therefore, we use the CAS probe for this study. In future

studies, we will analyze different datasets with CDP and FSSP. We add some discussion (Lines 364 - 366): "This new method can be applied to other datasets with different cloud droplet size probes (e.g., the Forward Scattering Spectrometer Probe, FSSP), since the new definition is based on theoretical understanding of entrainment-mixing mechanisms, which is not limited to the dataset used here."

2. New microphysical measure of mixing degree:
   The formula (14), at line 233, for new microphysical measure should be discussed in data and method section along with other methods.
   Reply: According to the reviewer's comment, the formula for the new microphysical measure is discussed in data and method section (Lines 142 - 147): "A new dimensionless HMD (ψ_5) is introduced to quantify the different entrainment-mixing mechanisms:

$$\psi_5 = dis(r_{vc}^{\ 3}) / dis(\mathrm{LWC_c}), \tag{7}$$

   where *dis* represents the relative standard deviation expressed by the ratio of standard deviation to the average value over each level. During entrainment-mixing and evaporation processes, $\mathrm{LWC_c}$ always decreases but r_{vc} decreases in the HM mixing and remains constant in the extreme IM mixing. Therefore, the extreme IM mixing corresponds to ψ_5 = 0, and the larger the value of ψ_5 is, the more HM the entrainment mixing is. More discussions on ψ_5 are given in Section 3.2."

   This new method does not give any theoretical basis like the other mixing degree methods. This is a relative measure of HMD as deviation from the extremely inhomogeneous mixing line. But, does not quantify the amount of homogeneous mixing precisely. A critical value for homogeneous mixing cannot be inferred from this method. This is a disadvantage of this method.
   Reply: We agree with the reviewer that the newly defined measure is a relative measure of homogeneous mixing degree (HMD) as deviation from the extremely inhomogeneous mixing line, but does not quantify the amount of homogeneous mixing precisely. This is indeed a disadvantage of this method. We have added the above discussions in the revised manuscript (Lines 356 - 358): "The new homogeneous mixing degree defined here is a relative measure of homogeneous mixing degree as deviation from the extremely inhomogeneous mixing line, but does not quantify the amount of homogeneous mixing precisely."

   Furthermore, the standard deviation of mean radius and LWC increases due to differences in mixing states (having different history of mixing) and in-cloud activation of CCN. These points should be discussed properly in the results.
   Reply: Yes, we have added the related discussion in Lines 358 - 361: "The relative dispersion of volume-mean radius and liquid water content increases due to differences in mixing states (Khain et al., 2018) and in-cloud activation of cloud

condensation nuclei (Derksen et al., 2009), which affects the calculation of the new homogeneous mixing degree."

3. Although, there have been several reports on HMD using in situ observations, a limitation of such quantification is missing. Like Khain et al. 2018 pointed out the drawback of mixing diagram to quantify HMD using in situ observations due to transient mixing state. Some discussion is needed on this point.
   Reply: Thank you very much for pointing out this. According to the comment, we have added some discussion (Lines 361 - 364): "As pointed out by Khain et al. (2018), the mixing diagram has limitations when it is applied to analyze entrainment-mixing mechanisms using in situ observations, due to transient mixing states."

Other minor corrections are

4. Line 88: Sentence is not clear.
   Reply: The sentence is revised (Line 88 - 90): "The Cloud and Aerosol Spectrometer (CAS) probe measured size distributions in the radius range of 0.29 - 25.5 μm at the frequency of 10 Hz. The data in the radius range of 1.0 - 25.5 μm are used to calculate microphysical properties, i.e., number concentration (n_c), liquid water content (LWC_c) and volume mean radius (r_{vc}).".

5. Line 135: eq (5): Express the log values clearly for example ln (nc)
   Reply: The log values are clearly expressed in Eq (5), according to the comment:

$$\psi_3 = \frac{\ln(n_c) - \ln(n_i)}{\ln(n_h) - \ln(n_i)} = \frac{\ln(r_{vc}^3) - \ln(r_{va}^3)}{\ln(r_{vh}^3) - \ln(r_{va}^3)}. \quad \text{(R1)}$$