Review of "Use of Large-Eddy simulations to design an adaptive sampling strategy to assess cumulus cloud heterogeneities by Remotely Piloted Aircrafts" by Maury et al. (amt-2021-20)

The manuscript assesses how Remotely Piloted Aircrafts (RPAs) could be applied to measure the spatial and temporal distribution of liquid water in shallow cumulus clouds. Within high-resolution large-eddy simulations (LESs), virtual RPAs mimic measurement patterns, which allow the authors to evaluate the potential of this promising measurement approach for static and a temporally developing cloud.

Overall, the study is very interesting, and the presented approach could be beneficial to measure small-scale heterogeneities in clouds. However, the manuscript requires substantial major revisions to present a convincing sampling strategy and to reach a state acceptable for publication in Atmospheric Measurement Techniques. More details follow below.

Major Revisions

Effective resolution. The authors need to determine an effective resolution of the suggested sampling strategy to assess whether it can measure small-scale heterogeneities in clouds. The mixing timescale $\tau_{mix} = (l^2/\varepsilon)^{1/3}$ might be useful here (Baker et al. 1984). τ_{mix} indicates how fast a heterogeneity with a typical lengthscale l decays to the Kolmogorov lengthscale for a turbulence kinetic energy dissipation rate ε. Figure 11 shows that for estimating the total LWC, at least 300 s of measurements are necessary (1 RPA + GPR). If you equate this to the mixing timescale and solve for l, one yields an effective resolution of 164 m. (I used $\varepsilon = 10\ \mathrm{cm}^2\ \ \mathrm{s}^{-3}$, which is a low but typical value for shallow cumulus; more accurate estimates of ε might be available from the LES model's subgrid scheme.) Accordingly, only heterogeneities larger than 164 m can be assessed reasonably, which is probably too large to investigate the dynamics of entrainment and mixing, which are associated with lengthscales ≤ 100 m (e.g., Bodenschatz et al. 2010). This quick calculation indicates that several RPAs, which can shorten the time to measure the cloud, are necessary to gain reasonable insights into the small-scale dynamics of clouds, and the authors have missed the opportunity to include more RPAs in their analysis.

The use of multiple RPAs. The number of RPAs is probably insufficient to resolve the cloud at spatial scales relevant to entrainment and mixing, as indicated above. Furthermore, the authors also conclude that one RPA is insufficient for assessing a developing cloud (ll. 348 – 351). Accordingly, why do the authors not investigate the impact of a potentially much larger number of RPAs? The presented workflow for determining the virtual RPA measurements could be repeated several times with different initial locations without too much additional work. The results would probably assess how the results improve as a function of the number of RPAs, and how many RPAs are at least required to sample a developing cloud. This information is highly relevant for planning real applications of RPA sampling, and need to be included in this manuscript.

Minor Revisions

L. 5: Why are microscopic properties disregarded here?

Ll. 30 – 31: Clarify "climate responses".

L. 32: Entrainment and mixing create heterogeneities.

Ll. 36 – 39: Sub-grid scale liquid water content is not a quantity that is predicted in most LES models.

L. 42: A more appropriate reference for CARRIBA is Siebert et al. (2013).

L. 47: Regarding the oversampling of the cloud core, you should cite Hoffmann et al. (2014) here.

L. 54: As above, sub-grid scale variations in the cloud droplet number are rarely predicted in LES.

L. 98: Why did you use only a one-moment microphysics scheme? Turbulent mixing, which is a potential subject to be addressed within the presented framework (l. 32), is known to change the droplet number significantly (e.g., Baker and Latham 1979), which requires a two-moment microphysics scheme to be represented correctly.

L. 100: In the literature, the term "saturation adjustment" is more frequently used than "all-or-nothing". Please consider changing.

Ll. 104 – 107: What do you expect from the larger domain? Why do you introduce that smaller domain at all?

L. 109: The term "High Frequency Simulation" is misleading. The simulation is not high frequent; the output of data is. I suggest "High Frequency Sampling" as an alternative.

Ll. 116 – 117: It is well known that the TCC increases for higher resolutions. I suggest citing Matheou et al. (2011) here.

L. 158: How do you calculate the geometric center? The red dot in Fig. 3 does not look very much in the geometric center. In the conclusions, you state that the geometric center is weighted by the LWC, which is relevant information but should be stated here already.

Ll. 192 – 193: Clarify how the large standard deviation highlights the role of clouds in the transport of water in the atmosphere.

L. 204: How do you define microphysical properties?

Ll. 258 – 268, 373 – 376: Is the discussion of simple geometric forms necessary? I would omit these lines in the revised manuscript. Why do you address Fig. 10 before Fig. 9?

Fig. 10: The colors stated in the caption do not correspond to the colors assigned in the line labels.

L. 290: Clarify what do you mean by 1-RPA and 2-RPA. I assume that the latter describes the investigation with two RPAs, but it is not stated explicitly.

Fig. 11: It might be helpful to add the number of transects on the x-axis, in addition to time.

Ll. 324 – 325: Does this statement refer to N2? This is, however, already shown in Fig. 12. Please clarify.

L. 333: The static cloud has been discussed in the Sections 3.3.1 to 3.3.4.

L. 340: For clarity, consider calling the four "instances" "timeframes".

Fig. 14b: Why is this panel not discussed in the text? And why are there two sets of starting and ending points?

Ll. 350 – 351: A potentially better sampling strategy has not been discussed. Omit this sentence.

Technical Corrections

Ll. 2 and 26: Decide on "earth" or "Earth".

L. 14: "maritime" instead of "oceanic".

L. 19: "distribution", not "distributions".

Ll. 133 – 142: The figure uses a slightly different notation for the points in time. (E.g., t=0 and not t0.)

L. 150: "RPA" not "RPAS".

Ll. 221 – 225: Where are the panels a to c in Fig. 6?

L. 241: Where is the red arrow in Fig. 7a? And where is Fig. 7a?

L. 252: Check the citation style: "Hoffmann et al. (2014)" instead of "(Hoffmann et al. 2014)".

L. 271: Add a blank after "profile."

L. 278: There is one parenthesis ")" too many.

References

Baker, M. B., & Latham, J. (1979). The evolution of droplet spectra and the rate of production of embryonic raindrops in small cumulus clouds. *Journal of the Atmospheric Sciences*, *36*(8), 1612-1615.

Baker, M. B., Breidenthal, R. E., Choularton, T. W., & Latham, J. (1984). The effects of turbulent mixing in clouds. *Journal of Atmospheric Sciences*, *41*(2), 299-304.

Bodenschatz, E., Malinowski, S. P., Shaw, R. A., & Stratmann, F. (2010). Can we understand clouds without turbulence?. *Science*, *327*(5968), 970-971.

Hoffmann, F., Siebert, H., Schumacher, J., Riechelmann, T., Katzwinkel, J., Kumar, B., Götzfried, P. & Raasch, S. (2014). Entrainment and mixing at the interface of shallow cumulus clouds: Results from a combination of observations and simulations. *Meteorologische Zeitschrift 23 (2014)*, *23*(4), 349-368.

Matheou, G., Chung, D., Nuijens, L., Stevens, B., & Teixeira, J. (2011). On the fidelity of large-eddy simulation of shallow precipitating cumulus convection. *Monthly Weather Review*, *139*(9), 2918-2939.

Siebert, H., Beals, M., Bethke, J., Bierwirth, E., Conrath, T., Dieckmann, K., ... & Wex, H. (2013). The fine-scale structure of the trade wind cumuli over Barbados–an introduction to the CARRIBA project. *Atmospheric Chemistry and Physics*, *13*(19), 10061-10077.