The evolution of warm rain in trade-wind cumulus during EUREC^{4}A

This paper characterizes the thermodynamic and microphysical variabilities within shallow trade cumulus clouds near Barbados, primarily using aircraft observations from the EUREC^{4}A campaign in 2020. The study analyzes shallow cumulus precipitation structures in relation to aerosol loadings and cloud mesoscale structure. Key findings show that maximum rain intensity is associated with cloud aggregation rather than aerosol loading, though aerosols impact cloud depths. The in-depth characterizations of aerosol-cloud microphysical and macrophysical processes using various in-situ and remote sensing platforms are valuable for future modeling studies and the broader shallow cloud research community.

However, the paper currently lacks structure and logical flow. The paragraphs do not transition smoothly, and the objective of the paper is not clear until much later in the text. Some major revisions are necessary to improve clarity and readability. Below are some major and minor comments that suggest more organization and some clarification regarding key results. With this, I am recommending a major revision.

Major comments:

1. The premise of the paper should be clarified early in the introduction. The interest in examining the effects of aerosol on precipitation intensity in different conditions and clustering should be stated upfront. Reorganize the introduction into three broad sections: Research topics and science interests, previous works and their highlighted results, and current research objectives. In general, ensure each paragraph and sections end with statements leading to the next paragraphs and sections. This will help improve the readability and comprehension.

   AC: We have restructured the introduction and made additions based on the recommendations. We now state the aims early in the introduction and have clarified the goals of the research more clearly. We also made changes to improve the readability of the introduction.

2. Include all instrumentation and measurement details in section 2. Include the wind and temperature measurements description that is in section 3 right now. Elaborate the Twin Otter and HALO flight details, days, number of flights, duration, distance between HALO and TO flights etc. Write the abbreviations of all the instruments, campaign, satellite etc. used in this study. Currently, many of them are just mentioned as acronyms.

   AC: We merged section 3 with section 2 to improve the structure of the measurement descriptions and combine the wind and temperature information with all the other descriptions. The flight details have been stated including the date range and number of flights. We also refer to existing published research describing the EUREC4A measurement domains and the various instrument platforms involved in the project and their proximity to each other. We have checked to make sure abbreviations for all of the instruments are given where appropriate.

3. Section 2 includes all the microphysical probes on board the TO. However, the only ones used in this paper are PCASP and CDP. Could the analysis include the precipitation rates and precipitation drop size distribution evolution from clean to polluted cases using the 2DS and HVPS samples? This could confirm the linkage of aerosol loading and precipitation intensity using independent platforms.

   AC: We have completed new analysis to calculate the rain rates in the low and high aerosol regimes using the HVPS drop size distribution. This is described in the in-situ measurement

section. We found that the aerosol regime doesn't appear to control the precipitation intensity. The main finding is that the mesoscale cloud structure does influence the precipitation intensity, with the larger mesoscale cloud structure (flowers and fish) associated with the greatest rain rates.

4. Expand the discussion to link findings to tie it up with introduction. State the limitations of the approach and suggest the scope and need for future research.

   AC: We have expanded the discussion and added limitations and some ideas for potential modelling work to build on the observations from this paper.

Minor comments:

- Line 41: Write the full form of EUREC4A here since you mention it for the first time. State that the manuscript is based on the EUREC4A datasets.

  AC: We have defined the acronym and made sure it is consistent throughout the manuscript.

- Line 50: "*The motivation for previous projects and the work presented in this paper focus on the importance of the cumulus clouds in the trade wind region around Barbados and the difficulty they pose for models that need to parameterise clouds and atmospheric properties in such environments*." Clarify how your motivation and objective add to previous studies, the differences in methodologies, timescales, study areas, if any.

  AC: We have added a statement describing the way EUREC^{4}A adds to the previous studies in the final paragraph of the introduction.

- Line 143: The wind and temperature measurements are described in section 3. It should be part of section 2 along with all the other instrumentations.

  AC: The structure of paper has been modified extensively, with all the measurement information now described in section 2 along with the other instruments.

- Figure 8: The dust aerosols described throughout the manuscript is referred to as 'silicate (mineral marker)' in the legend. Adding 'dust aerosol' in the legend will be helpful. Similarly, add 'biomass' in the legend as well beside 'organic' for consistency

  AC: We have included these in the legend.

- Figure 8: Change 'LAAPTOF' in the figure description to 'LAAP-TOF' for consistency.

  AC: This has been changed.

- Line 186: "*The Twin Otter aircraft performed fly-by manoeuvres of RP during each of its flights and agreement between aerosol measurements made by the aircraft and at BCO (not shown) were found to be generally excellent across a range of different instruments and measurement techniques*". Could the list of instruments at BCO used for this verification be listed in section 2?

  AC: As we do not show the inter-comparison we have now decided to remove this statement.

- Figure 9: The percentiles of the CDP concentration could also be included on the y-axis. Mention if each point is representative of each flight.

  AC: This has now been removed as part of the revisions to improve the structure of the paper.

- The HALO flights and instrumentations including HAMP used in this study should also be included in section 2.

  AC: This manuscript has been edited to make sure all of the relevant information about the instruments and measurement platforms is contained within section 2.

- Figure 10a: There is only one panel, so 'a' should be removed.

  AC: This has been removed.

- Line 237: Rephrase "For example, the dust that is transported in a relatively deep layer across the Atlantic Ocean from Africa."

  AC: This has been rephrased.

- Line 249: Is the higher CTH spread for 9 Feb compared to 2 Feb case linked to the presence of biomass and dust?

  AC: It's unclear whether this is linked to the presence of different aerosol types. It's likely to have been driven by the thermodynamic profile of the atmosphere in the region being conducive in some places to deep convection.

- Use CTH instead of cloud-top heights consistently.

  AC: This has been checked and CTH used throughout.

- Line 264: Could the reflectivity at the lowest radar range gate be used to see if aerosol concentration (N_a) still does not correlate with reflectivity? Additionally, could the 2DS and HVPS observations mentioned in section 2 be used to compute rain rates, and then correlated with N_a to re-confirm this result

  AC: There is attenuation to consider for the lowest levels in particular. In any case the reflectivity values within the cloud are a better representation of the warm rain process due to evaporation below cloud base.

  Figure 13: What is the altitude of radar reflectivity shown in the figure? In Figure 11, the radar reflectivity closest to the surface seems to have higher reflectivity on 2 and 9 February compared to 28 Jan and 13 Feb. If so, then could the cloud base reflectivity (and hence rain intensity) be correlated with N_a? A scatter plot showing the cloud base reflectivity/rain rate/CTH vs N_a would be more intuitive (instead of time series) for emphasizing the key points here.

  AC: The statistics were calculated using all the radar reflectivity values at all altitudes for a particular day. The exception is that the large values near the surface where there were no clouds above were excluded. The reviewer makes a good suggestion about a scatter plot. However, we opted for the analysis shown mainly because of presentation, but also because: a) there are some relatively high reflectivity values close to the surface on 13 Feb; b) there is attenuation to consider; and c) the statistics are better if all reflectivity values are included.

We included the first part of this answer in the figure caption.

- For figures 10 and 13, include the correlation coefficients between N_a and CTH and reflectivity for low and high N_a It is hard to follow the boxplot median lines as a function of GRIMM N.

  AC: To make the correlation between the N_a and CTH clearer we have split the regimes and calculated the median CTH for the high and low aerosol periods. We found the CTH to be ~ 300 m greater in the high aerosol regime. This has been included in the paper.

- Figure 14: Could the panels be arranged by date or N_a for better readability?

  AC: The panels have been split by N_a.

- Line 300: "*However, the two groups achieve similar maximal values regardless of the initial conditions at cloud base and rate of increase with altitude*." This line contradicts the paragraph at line 286. This earlier paragraph says that the Reff is similar at cloud base but the rate of increase in Reff is higher in low N_a But line 300 conveys that regardless of initial (Reff) conditions at cloud base, the rate of increase is the same. Could this be clarified?

  AC: We have clarified that the reason the cases achieve similar Reff is due to the higher CTHs in the higher aerosol regimes.

- Paragraphs after line 313 do not fit into the section 6 headline. Use new section for this.

  AC: This has now been combined with the remote sensing section.

- Tie the Figure 16 and 17 results with the previous results. For more context, the essential features (e.g., reflectivity, spatial width, rain rates) of the mesoscale structures (fish, flower, gravel, sugar) should be defined in the introduction. Later, in the results sections the dates featuring each of these structures should be indicated both in text and figures.

  AC: We have now defined in detail the different mesoscale cloud structures (fish, flowers, gravel and sugar) in the introduction. The different mesoscale organisation is indicated in Figure 16 and with the manifold highlighting the continuum of cloud scenes that have variation between the more strictly defined cloud groups.

- What is the significance of the x- and y- axis in Figure 16? Is the shape of the map indicative of anything? Some clarity would be helpful for readers not acquainted with neural networking.

  AC: We attempt to describe this difficult concept in the manuscript, the axes represent the embedding vectors where cloud scenes identified as similar in nature by the neural network are mapped onto the manifold using these vectors.

- Figure 17 and paragraph at line 327: How does this figure tie in with the previous sections? Among all the days shown in the figure, 13 Feb with fish clouds seems to have the least rain rate for a given area. However, in the previous paragraph fish clouds are linked with higher reflectivity which should be a proxy for higher rain intensity. Clarification will be helpful.

  *AC: There will be some variation in rain rates even within a particular cloud group. The lower rain rates on 13 Feb in the fish clouds that were presented in Figure 17 also tie in with those presented in new rain rate figure **X**, with the in-situ measurement observing higher rain*

rates in the flowers on 7 Feb vs the 13 Feb fish case. This is also consistent with the data presented in Figure 17.

- Why are the other days described in the rest of the paper (26,28,31 Jan, 2,5 Feb) not shown in Figure 17?

  AC: Unfortunately due to delays the Poldirad radar did not arrive until later in the project so we only present the data we had available.