Review

Life cycle of a flower cloud system during the EUREC4A field campaign

By Zhiqiang Cui et al.

Mesoscale cloud patterns of shallow convection are currently studied to great detail in all climate regions from polar cold-air outbreaks to green cumulus over the Amazon. In the downstream Atlantic trades, Stevens et al. (2020) observed four frequently occurring patterns: Sugar, Gravel, Flowers and Fish. This manuscript focuses on the Flowers pattern and describes based on a case-study the evolution of a cloud system within this pattern by utilizing a wide range of observations from the EUREC4A campaign.

Understanding the evolution of these mesoscale patterns is an important factor to simulate the cloud radiative feedback. As Bony et al. (2020) pointed out, each pattern is associated with a unique cloud radiative effect. Any distribution changes of these patterns that can occur due to e.g., shifts in storm-tracks or a widening of the tropics (Schulz et al., 2021), can potentially affect the radiation balance. As a consequence, these cloud patterns need to be correctly represented in both climate models for future projections and large-eddy simulations to gain a better process-understanding of their mesoscale dynamics.

The manuscript describes the life cycle of a cloud system within a Flowers pattern to great length both at the mesoscale with the help of geostationary satellite images and retrievals as well as on the cloud-scale with in-situ flight measurements and dropsonde data. While the description presented here is very elaborate, the manuscript should be more condensed and have its main audience in mind. Particularly modelers are interested to have a benchmark dataset or key parameters and their values as a reference to improve their simulations. The manuscript needs to better carve out these key parameters and be more specific in the conclusion to become impactful. That said I'm convinced that the topic of the paper will be a welcomed study to the community. As the framing needs to be improved and the list of comments is relatively long, the manuscript needs major modifications.

General Comments

- The manuscript would greatly improve by being more concise and more fluent. Paragraphs are often stand-alone and not well connected into the flow of the manuscript. An example is for example the 3rd and 4th paragraph in the introduction that mainly review cloud controlling factors and aerosols without being a strong part of the motivation of the manuscript.
- Please gear towards modelers and emphasize that this is observational work. The manuscript should provide clear key parameters and their values. While this is a case study and cannot be generalized, key parameters of each stage in the life-cycle shall be summarized. This boils down to the question of what added-value does this manuscript provide if someone wants to set-up and compare their simulation with observations or study their dynamics more generally.
- The manuscript would greatly benefit by being carefully read by an English native speaker (e.g. one of the co-authors).

- Plenty of studies came out of the EUREC4A field campaign and several of these touch on aspects of this study as well, in particular Feb 2. The manuscript would greatly improve if it would embed previous results to strengthen its hypotheses. Examples are the mesoscale circulations and subsidence measured by George et al. (2023), the cold pool analysis by Touze-Pfeiffer et al. (2022) and the radiative cooling profiles by Albright et al. (2021). All of these studies present observations of Feb 2nd and are hardly mentioned in this manuscript. Cold pool dynamics that Dauhut et al. (2023) for example mentioned are described but hardly discussed in terms of their potential role although they seem to be essential for this pattern.
- The aerosol section is very limited and less mature. I would encourage the authors to exclude any aerosol related analysis from this study.
- Precipitation, which is closely connected to cold pools and has been pointed out to correlate with Flowers has been mostly ignored. An analysis of the precipitation, e.g., from satellite products or research vessels equipped with radar (e.g. Fig 8 of Touze-Pfeiffer et al. (2022)) should be included.

Specific comments

- Consider capitalizing the mesoscale pattern names and make them italic for better readability
- A reference to the PMA instrument suit and its measurements is missing in the data section.
- Further, the manuscript mentions the SAFIRE-CORE dataset, which should be cited and explained in the data section as well.
- Data availability section:
    - Please provide DOIs to the specific datasets used. URLs are not a permanent identifier and, in this case, do not point to the specific versions used.
        - DOIs of GOES-16 products used
        - DOI of JOANNE/dropsonde dataset
        - DOI of SAFIRE-CORE dataset if it has been used as indicated in the manuscript
        - DOI of ERA5 hourly data product
        - Any additional datasets
    - Code to reproduce results and figures is missing
- The number of figures needs to be drastically reduced. A few suggestions are proposed in the figure specific comments, but additional deletions/merges or moves to the supplement would benefit the focus of this manuscript.
- The manuscript is studying the life cycle of a cloud system within a Flowers pattern, which according to Vial et al. (2019) undergoes a diurnal cycle. However, the analysis here uses the foundation temperature of ERA5 which is lacking a diurnal cycle. Using the skin temperature might improve some of the robustness of arguments and should be used here instead. In-situ observations from ships would be even better.
- Dropsonde analysis section:
    - Here would be a good point to reference George et al. (2021)
    - 17 dropsondes have been selected but only 4 were mentioned in the manuscript (W1 – W4). All information about grouping and soundings at N, E, S end of the circle can therefore be discarded, including Fig. 17.
    - Fig. 18 c can be combined with Fig. 20, while Fig. 18 a,b,d can be deleted

Line by line comments

- L. 55: …inversion and keeps the boundary layer….
- L. 58: please use the word cloudiness instead of cloud
- L. 64: Aerosol is an other controlling….
- L. 70ff: The work of Mieslinger et al. (2019) would better fit into the previous paragraph and should be better integrated there.
- L.86: …edge only of one Flower cloud patch with the highest…
- L. 95: The Trade wind Alley is a jargon word that seems to be better described here by "downstream trades"
- L. 101: "the life cycle of an individual flower system has not been examined". While this is true, the work of Dauhut et al. (2023) and Narenpitak et al. (2021) should definitely be mentioned here. It should also be emphasized that this study uses observations.
- L.102: The outlook to "investigate favorable and unfavorable conditions for this flower system" is not given in the manuscript. Only one cloud system is observed and neither sensitivity runs are made nor are a significant number of cloud systems observed to correlate the cloud pattern with cloud controlling factors.
- L.108: Switch "Geostationary Operational Environmental Satellite-16 (GOES-16)" with "Advanced Baseline Imager (ABI)". It's the imager which provides images and not the satellite itself.
- l. 115: please add a reason for why band 14 has been used which is not in the clean infrared window but is affected by water vapor
- l.118f: please provide a reference for the mentioned algorithms
- l.137f: The circling strategy of the EUREC4A flights has not been used here and is unimportant for this manuscript. Please leave this out and rather explain how the inversion base and inversion top are derived from the dropsonde dataset.
- L.137f: George et al. (2021) seems to be a better reference to the JOANNE dropsonde dataset. If JOANNE has not been used here, it should be justified.
- L.142: …aerosol and among other atmospheric measurements….
- L.151: The C3ONTEXT dataset of Schulz (2022) could serve as a reference here to support the presence of a Flowers pattern.
- L.158: …GOES-16 ABI IR channel… it is the IR channel of the ABI and not GOES-16. Please adapt all occurrences in the script.
- L. 159: see above
- L.158: brightness temperature would be more informative and intuitive then radiance, especially with respect to model simulations. Please convert the radiances in the script to brightness temperatures.
- L.168: "Other studies used modified…". Unimportant references as only the Houze (2004) will be used. Consider writing "We adapted this system here under the assumption that Flowers are MCSs following Dauhut et al. (2023)"
- L.171: …divided into those three stages and based mainly on the area of the system."
- L. 178: … and highest inversion top (~3100m) was determined by…
- L.179: 19 UTC

- L.196: 0720 – 0820 UTC (separation is not visible at 0800 UTC)
- L.197: Figures 7a-7d).
- L.198: …The area to the east…
- L. 199f: “the two cloud regions merged at about 11 UTC.” This is vague and could be more specific. The clouds seem clustered already in 7a s there is no clear-sky separating them. Maybe one could say that by 11UTC a common stratocumulus has been developed.
- L. 215ff: Units are weirdly formatted here and throughout the manuscript. Please use the same font for µ as for other characters.
- L. 240ff: the “mean volume diameter” needs to be better defined as well as the entire PMA observations. A good place for this would be the data section.
- L. 250: where does the vertical velocity and LWC come from? Please define this in the data section.
- L. 250: at which altitude did the airplane sample these measurements? Was the flight level constant (above sea level or pressure)?
- L. 250ff: Figure 12 has been taken at 15 UTC, when the ATR has finished n2, which let me conclude that the highest values of LWC and upward motion were recorded at the WESTERN side of the cloud system, which would be in agreement with Dauhut et al. (2023).
- L. 251ff: this is too vague.
- L. 305: how are inversion top and inversion base derived from the dropsonde data? Please add this information to the data section.
- L. 351ff: What do change in boundary layer height due the authors expect from a change in sea surface temperature of 0.3K? It would be good to include here the CTH estimates from the satellite measurements and how much they changed to combine this paragraph with the earlier sections.
- L.369: please mention why these two levels are chosen. Are these inversion top and inversion base?
- L.371: it should be noted that the dropsondes were assimilated
- L.372: is this the absolute difference? Please clarify.
- L.378: mesoscale subsidence has been derived in George et al. (2023) and is part of the JOANNE dataset. It does not need to be speculated here. W4 seems to be from the last flight circle (Konow et al. (2021)). Looking at Fig. 1 of George et al. (2023) convergence exists in the afternoon flights at 2.5km. The claims should be in context to previous studies and here especially checked with the available data.
- L.380: “…revealed that the air above the cloud top descends along the downshear side of the cloud edge”. Overlying in my head to position of W4 and the cloud top height product, W4 does not seem to be in the downstream location but rather right in the convective core. Indicating the dropsonde positions in e.g. Fig. 13 would help to make or dispute this claim more objectively.
- L.381: The radiative heating profiles of EUREC4A have been calculated by Albright et al. (2021) and should be checked if they support the radiative cooling hypothesis.
- L.426 ff: This paragraph is mostly literature review and proposes vague future analysis for aerosol studies which have only touched upon at the beginning of

this paragraph. To make the manuscript more concise this paragraph and all aerosol analysis can be removed.
    - L.465: without denial experiments this is speculation
    - L. 481: …The data measured by HALO are openly available at the …
    - L. 465: "conditions that favored the cloud development included the enhanced moisture around the flower and the increasing aerosol optical depth near Barbados":
        - Whether these conditioned favored the cloud development is speculation, these factors might just coexist by chance, especially so for the AOD
        - Could it not be that the Flower itself and their mesoscale circulations create these enhanced moisture structures?
    - L. 468: This outlook includes a lot of elements that are already used in this study, like aircraft measurements and in-situ measurements of cloud microphysics. What specifically are the authors missing and hope to find in a second revision of these observations. Couldn't those features be described in this manuscript so that a future study can focus solely on the dynamics? What are "interesting features"? This goes back to the question what the main goal and audience of this manuscript is.
- Figures
    - Figure 1:
        - The synoptic chart with its fronts and coastlines does not match the underlying satellite image. Geographic features do not align.
        - Please indicate whether this is an AQUA or TERRA overpass
        - Please indicate the time of the overpass and the surface analysis chart
    - Figure 2:
        - …GOES-16 ABI imagery… Please add ABI here and in all other figure captions where applicable
        - Mixture of m=milli and m=meter is confusing. For better comparison with models the radiances should be converted to brightness temperatures and included as a legend
        - The subplots change size. This should be pointed out or be adjusted.
    - Figure 3:
        - …in Figure 2, and …
    - Figure 4:
        - Please indicate whether this is UTC or local time
        - Unit and label are missing in colorbar
        - It should be made clear that the CTH is derived from satellite products and is therefore affected by attenuation. E.g. the frequencies after 14 are dropping at below 2km presumably due to attenuation of the layers above. This should be emphasized as the paper will be a resource for models.
    - Figure 6:
        - Please improve the aspect ratio to 1:1 for longitude and latitude so that the cloud field is not skewed

        - The colorbar ticks are not meaningful and too precise. It would help to interpret the satellite images better by marking typical cloud top heights at the lifting condensation level and inversion height.
        - A sequential colormap would help aid the reader to better distinguish the heights and in particular their differences.
        - Labels of the lat-lon grid are too small
        - Turn off the interpolation of the observations to reduce the number of introduced artefacts.
        - Caption: …cloud top height product between…
    - Figure 7:
        - It would be helpful to see the radiance threshold lines here as well, in particular to better follow the merging argument of the cloud cells
    - Figure 8:
        - Change colorbar positions so they match the image columns (e.g. switch optical depth and cloud top height)
        - Include radiance threshold outline
        - Switch off interpolation of the values here and in other figures where applicable
        - Please include the times of the snapshots on the left hand side to more easily find the timestamps of each satellite image.
    - Figure 9:
        - Caption: change “data” to “instrument” if this is true? Measured with data sounds incorrect.
    - Figure 10:
        - Color legend is missing.
    - Figure 11:
        - Is this a visible ABI image?
        - Increase font size of labels and ticks
        - This Figure could be combined with Fig. 13 by including the ATR track in each subfigure
        - Please include the position of the aircraft at the time when the satellite picture was taken.
    - Figure 12:
        - The caption is claiming that LWC is coming from the SAFIRE-CORE instrument, but this is in contradiction with the description in Bony et al. (2022)
        - SAFIRE-CORE is first mentioned here and not introduced beforehand. No reference is given.
        - Please add a horizontal line at a vertical velocity of 0 to better see where velocities are positive or negative.
        - Please write the time in the format HH:MM instead of MM:SS
    - Figure 13/14/15/16:
        - All these Figures can be combined to one and be presented similar to Fig. 8 or even a Fig. 8 continued.
        - The temporal frequency the satellite images are shown at could be reduced to 1h. I do not see the additional value of 30min snapshots.
    - Figure 18:

        - Consider using km instead of m
        - Please indicate the 700 and 750 hPa levels
    - Figure 19:
        - Increase labels and ticks
    - Figure 20:
        - Brackets in unit label should be removed
        - Consider using wind speed and wind direction as labels
    - Figure 21:
        - …The dataset used is ERA5 at 0.25 deg resolution.
        - Units are missing
        - Consider using the term “Hovmöller diagram” instead of “longitudinal-temporal variations”
        - Please clarify whether the dataset is shown at a constant latitude or whether the central latitude of the cloud system is followed as well.