Final response
(Manuscript "EGUSPHERE-2025-374")
Reviewer 1

Sarah Brüning and Holger Tost

May 23, 2025

1 Introductory remarks

We would like to thank the reviewer for taking your time to write the constructive and detailed feedback. In the following sections, we address all comments. For every comment, you can find (1) the comment, (2) the author's response (both with lines from initial manuscript), and (3) the author's changes in the revised manuscript.
The lines given for **author's changes in the manuscript** refer to the lines in the **revised manuscript**.

Based on all referee comments, we focus the revision on improving the clarity of the written expression for, i.e, the description of our methods and the results. As suggested in your review, we aim to include a more detailed acknowledge about the subjectivity of our object-based detection approach and derived cloud life-cycle. While the narrative and main points of the manuscript did not change, we aim to focus on directly describing observed results, in particular regarding the connection between convective cores and cloud properties. Based on both referee comments, we agree the term "seasonal" may be misleading for the depicted period of only six months. Instead, we describe "monthly" changes, which we observed during the period. Moreover, we changed the abbreviation "DCC" to "cores" to align with our manuscript for Part 2 of the study ("EGUSPHERE-2025-376").
We changed the figure labels in the following way:

- 1 -> 1
- 2 -> 3
- 3 -> 2
- 4 -> 4
- 5 -> 5
- 6 -> 6
- 7 -> 7
- 8 -> 8
- 9 -> 10
- 10 -> 11
- 11 -> 12
- 12 -> Removed
- 13 -> 13
- 14 -> 15

- 15 -> 16
- 16 -> 17
- New: 9 (Distribution of cloud tracks grouped by the surface type: month, daytime of first detection)
- New: 14 (Correlation matrix for cloud properties, core properties, and life-cycle statistics for all cloud tracks, clouds with a single core, and clouds with multiple cores)

2 General comments

- **Comment**: The paper's perspective might be broadly categorized as an "object-based" scientific worldview. The basic idea is that atmospheric dynamics are best understood as interactions between discrete components – clouds, MCSs, DCCs – and therefore the geometry and spatiotempral distribution of such objects is of key importance in our scientific understanding of weather and climate. Although concepts like MCSs and DCCs are useful and important, in my opinion it is crucial to remember that such concepts are not fundamental and represent a subjective, imprecise, and qualitative description of the atmosphere. The reality is that the atmosphere is made up of continuous three- dimensional fields of matter and energy. This may seem like a pedantic philosophical point on my part, but the implication is substantial: quantitative object-based results such as those presented here are likely strongly dependent on the subjective definitions and thresholds used (specific examples are below). The issue is not that a given threshold might be "wrong," but rather that any threshold will be imperfect given that the basic object being defined (e.g. an MCS) is largely subjective in the first place. Because the objects under consideration (MCSs, DCCs) are fundamentally qualitative concepts, any study must introduce subjective thresholds and definitions to obtain quantitative statistics. Some metrics, such as cloud area, will obviously depend strongly on the threshold used to define cloud. Many other metrics, even some that seem at first glance less subjective, will also be sensitive to thresholds. For example, any cloud with an eccentricity higher than .75 is split into two clouds if the cloud has a "neck", for example if the cloud is hourglass-shaped (Sect. 3.1.2). This is performed in order to avoid "incorrect label assignments" (L139). Statistics such as number of cores per cloud, mean eccentricity, mean cloud size, cloud/core area ratio, etc. will all strongly depend on whether this step is performed or if the threshold of .75 was changed. It should be stressed that the problem is not that one method might be "incorrect" as implied by L139. Rather, the act of dividing an atmospheric volume into discrete clouds is a subjective process that imposes an artificial discrete framework on a continuous field. Discrete categories do not exist in the real atmosphere. To address the above observation I do not suggest any major revision of the methodology, but I would like an acknowledgement about the subjectivity of the chosen thresholds and at least some discussion about the inherent subjectivity and imprecision of dividing a continuous field into discrete objects.
  Author's response: We thank you for your comment and agree with you about the issues that may be connected with concepts that divide the atmosphere into qualitative categories. In the revised version, we try to point out more clearly the subjectivity of our object-based object with fixed thresholds and the derived life-cycle statistics. Also, we will add a more detailed description of the uncertainties and limitations to provide a better acknowledgment of this inherent subjectivity.
  Author's changes in the manuscript: Throughout the text, and in particular in Sect. 3 (Methods) and Sect. 5 (Discussion), we address the subjectivity of the approach more directly. You may find examples, e.g., in lines 136-140: "The workflow to identify possibly convective trajectories consists of three steps: detecting cloud features by their centroid's position, segmenting the associated cloud field for each centroid, and linking segmented objects through time (Figure 1, a–c). Moreover, we aim to separate cloud clusters that are only connected by a few pixels in the horizontal and vertical dimensions (Oreopoulos et al., 2017). The workflow of this object-based approach is depicted in Fig. 1 and will be explained in the following paragraphs.", lines 148-153: To identify potential cloud structures, we apply a fixed threshold of –15 dBZ to distinguish signals of hydrometeors from background noise in the radar reflectivity data (Marchand et al., 2008). While this threshold is only moderately restrictive — allowing for the inclusion of short-lived or weak features — it is intentionally chosen to capture the full spatio-temporal evolution of convective clouds between development and dissipation stage (Esmaili et al., 2016)", or lines 139-145: "The framework, while enabling detailed analysis of convective cores, has limitations. The predicted 3D cloud fields represent model-based approximations rather than direct

observations, reflecting patterns learned by the ML model. Additionally, using fixed thresholds in the object-based detection may oversimplify complex structures associated to clouds in the atmosphere. Nonetheless, we may employ the data to enable a large-scale, high-resolution tracking of convective systems over the tropical Atlantic and continental Africa."

- **Comment**: 6 months of data is not enough to get meaningful results on the seasonal characteristics (Sect 4.2.2, L366-L374, conclusion). Each season (spring and summer) have an N of 1, obviously not statistically robust. This is clearly seen in the 7 day means in Fig 11d, where there is clear variability due to the subseasonal meteorology that has a larger magnitude than any seasonal trend (note how non-smooth the curves are). Recommend either removing these sections or analyzing at least decades of data
  Author's response: We agree that the period is not sufficient to derive a statistical significant climatology of the seasonal or annual cycle of convection. In our study, we compare the two seasons (March-May, June-August) to showcase changes in the depicted period. We revise the manuscript to point out our goal more clearly (which is not an analysis of seasonality in statistical sense, but to highlight the findings achieved with our approach).
  Author's changes in the manuscript: Please see, e.g., Sect. 2, lines 74-79: "Our objective is to detect and analyse convective clouds and their life-cycles by a six month period between March and August 2019. This period was selected to highlight key characteristics of 3D cloud structures across different surface types within the AOI. Particular attention is given to the seasonal northward migration of the Inter-Tropical Convergence Zone (ITCZ) and the onset of the West African Monsoon (WAM). Since the WAM plays a critical role in shaping West Africa's climate and is responsible for a significant portion of the annual rainfall in the AOI, its arrival is expected to enhance the frequency of convective cloud formation (Andrews et al., 2024; Kniffka et al., 2019)." or Sect. 5.2, lines 506-510: "Seasonal variability in tropical convection has been highlighted in past studies. For example, multi-core systems often persist overnight during the onset of the West African Monsoon (Futyan and Genio, 2007). During this period, convection may frequently initiate over high terrain and propagate downslope at night under katabatic flow (Nicholson, 2018). While our results may be influenced by interannual variability, as the dataset spans only one year and does not capture a full annual cycle, we may observe temporal changes in cloud and core properties between March and August."

3 Specific comments

In the next section, we shortly address your specific comments. Changes will be added in the revised manuscript.

- **L77**: "subject to a spatio-temporal sampling in either dimension" is unclear but reads to me as just saying that spatial and temporal resolutions are finite... which is obvious and applies to all data, what did you mean?
  Author's response: In the original manuscript, we wanted to point out that active sensors provide detailed information on the vertical column, whereas passive sensors have a higher coverage of the horizontal dimensions (longitude, latitude). However, no sensor covers all dimensions while achieving a high temporal resolution and broad spatial coverage (i.e., like a global 3D sensor). We change the sentence to be more clear.
  Author's changes in the manuscript: Sect. 1, Lines 56-59: "Active and passive sensors contain important vertical or horizontal information, but are limited in their spatial and temporal coverage (active) or offer only an approximation of the vertical column (passive) (Masunaga and Luo, 2016; Taylor et al., 2017). To address this gap, we apply a machine learning (ML) framework to reconstruct contiguous 3D radar reflectivity fields from 2D satellite data (Brüning et al., 2024). "

- **L79-85**: I assume that Cloudsat is only used during ML training and only the geostationary data is used throughout the study. This is not clear in L79-85 and also 424, which imply your data are superior because they use multiple sensors ("Compared to using data from a single sensor, our perspective allows..."), which is not true. I don't see how I could be wrong here given that the data resolution is 15 minutes whereas Cloudsat's temporal resolution is roughly 16 days, but please clarify.
  Author's response: The ML model is trained using MSG SEVIRI channels to predict the vertical cross section of the CloudSat CPR containing radar reflectivities (hence, the model is validated against these cross sections). To receive pairs of MSG SEVIRI patches and the corresponding CloudSat cross-section, we search for overpasses of CloudSat along the domain in the tropical belt. Due to the symmetrical architecture of the Res-UNet, it may predict not only the reconstructed cross-section, but a contiguous 3D image. These predicted data incorporate

information from both sensors to represent the horizontal and vertical distribution of the cloud field (which comprises, for the final output of merged patches, 60°N–60°S and 60°E–60°W over 90 height levels between 2.4–24 km height). The predictions keep the temporal resolution of MSG SEVIRI (15 minutes).
Author's changes in the manuscript: Please see Sect. 3.1 for a more detailed description of the machine learning model, e.g., lines 111-114: "The Res-UNet is trained to reconstruct CloudSat-like 3D reflectivity volumes with a horizontal size of 100×100 pixels and a vertical size of 90 levels. The predicted radar reflectivity values range from –25 to 20 dBZ and retain the 15-minute temporal resolution of the original SEVIRI input."

- **Fig 7/8**: There is a fair bit of discussion about land/sea differences, but I find all land/sea results so close that they appear statistically insignificant. For example, the largest differences are in the reflectivity in 7e. The largest difference to my eye looks to be about a quarter dBz, although it is claimed the mean difference is 0.5 dBz (L268). Both are much smaller than the RMSE error calculated from ML model validation, which is 3dBz (Table 2).
  Author's response: We agree and revise the description of the results.
  Author's changes in the manuscript: In Sect. 4.1, we revised the description of Figures 7/8, e.g., in lines 289-293: "Land–sea differences are more pronounced for single-core clouds. Despite expectations based on previous tropical studies (Deng et al., 2016; Takahashi et al., 2017), oceanic clouds often show stronger reflectivity and larger areas — though overall surface-related differences remain small. The lower number of land-based clouds may exaggerate statistical noise.". Further discussion may be found in Sect. 5.2, e.g., lines 510-514: "However, differences between monthly averages over both surface types remain small. Here, our results may diverge from studies that report more pronounced spatial and seasonal variations for convective clouds over land and sea (e.g., Takahashi and Luo (2012); Wilcox et al. (2023)). More striking than these surface-type induced differences in mean cloud properties are the contrasts between single- and multi-core clouds. Longer-lived, multi-core systems often exhibit repeated phases of growth (Takahashi et al., 2017)."

- **Fig 9**: In Fig 9, much is made out of a "bimodal distribution" in the time direction, which is technically visible but I suspect is not really statistically significant. To me it looks the valley between the peaks barely crosses a single contour in all cases, so it's not very clear. A much more striking result is the bimodal distribution in the reflectivity direction in 9k and l, where the valley is many contours below the peaks, and there is a big difference between multiple and single DCCs. This is not really discussed much and I would be curious to hear the author's take.
  Author's response: We agree and revise the description of (old) Figure 9. We checked the data to investigate the distribution in the reflectivity direction in 9k & 9l and found a bug in calculating the 2D densities in our former version that led to an overestimation of high values in the density histogram. We add an updated version in the revised manuscript. Here, the radar reflectivity does not reveal a bimodal distribution, but rather depicts the overall increase for multi-core clouds compared to single-core clouds as shown in Fig. 7. At the same time, the revised code fixed the apparent bimodal distribution of the area ratio (Fig. 10 m-p). In the revised version, there is no valley but rather a high variability for single-core clouds and a lower variability with overall lower values for multi-core clouds.
  Author's changes in the manuscript: Sect. 4.2.1 for a revised description of the findings observed in (new) Figures 10 and 11, lines 314-337.

- **Fig 9, 10**: Perhaps the most notable feature of figs 9 and 10 is that all the contours seem to approach a frequency value close to zero at hour 0 and 24. These plots should "wrap" such that the contours line up at that location, and they might, but the minimum in frequency there really looks spurious to me. I encourage the authors to check their code for why this is happening. (Note that the implication would be that almost no clouds live past midnight.)
  Author's response: Actually, we found clouds living past midnight (e.g., Figure 9, a–d). Hence, we suggest the problem lies within the visualization. In the original manuscript, we used hourly bins to calculate the density distribution, but included no cyclic point. We update the figure to wrap up hourly bins at nighttime. We revise the figure and its description to be more clear.
  Author's changes in the manuscript: See Sect. 4.2.1 for a revised version of Figure 10 and 11, lines 314-337.

- **L301ff.**: Some points in paragraph starting at L301 seem quite exaggerated: • "a bimodal distribution over the sea and a singular afternoon peak over land:" I don't see that at all. b (land) and i (sea) have similarly significant bimodal dists (neither is that significant). c (sea), g (sea), e (sea) all have nearly zero evidence of a bimodal

distribution. • “the afternoon peak is consistently more powerful (Figure 10,c–d)” there is no peak at all in c, and in d it is only one contour level. • “Cores are more extensive and persistent over land” actually both a/b and c/d show nearly the same core area over land/sea. The “persistent” claim is more correct.
Author’s response: We revise the results presented in this section and their description to be more clear.
Author’s changes in the manuscript: Please see Sect. 4.2.1 for the description of Figures 10/11. E.g., lines 325-333: "The diurnal patterns of core properties (Figure 11) largely mirror those of the cloud properties. Over land, core area peaks between 12:00–18:00 UTC for both single- and multi-core clouds. Over the ocean, single-core clouds show two peaks between 00:00–06:00 and 14:00–20:00 UTC (Figure 11, a–d). The core lifetime follows a similar pattern for single-core clouds. For multi-core clouds, cores over land show two peaks, while oceanic cores point out no clear diurnal variation for multi-core clouds (Figure 11, e–h). For single-core clouds, peaks of the core lifetime resemble the core area (Figure 11, a, e). The distribution of the core height follows those of the core area (Figure 11, m–p). On average, clouds with multiple cores have higher and more variable values for core area, lifetime, and height. In contrast, the area ratio is lower and has a weaker variability for multi-core systems. For single-core clouds, we observe an afternoon peak over land and nocturnal and afternoon peaks over the ocean. Multi-core clouds show a weak diurnal variation, particularly over the ocean (Figure 11, i–l)."

- **L218ff.**: MCS “cooling:” The lifecycle of an MCS is idealized as occuring in 3 stages, the first of which ends at maximum “cloud cooling,” calculated as a change between the 10km reflectivity between CI and the time step of interest (paragraph at L218). This tripped me up as the link between reflectivity and temperature changes is not at all obvious, especially when comparing to a baseline at CI where the cloud will often not even extend to 10km. I suspect the authors mean something more like “convective activity”. Just substituting this term would make a lot more sense in many places, but either way please explain what is meant further. (note the paragraph at L329 and Fig 13 will need to be changed, and other brief mentions elsewhere)
Author’s response: We add a more detailed explanation of the statistics to describe the cloud life-cycle in Sect. 3.6. Moreover, we agree the term "cooling" may be misleading since we do not assess any cloud temperature directly in our study. Instead, we analyse the development stage of by calculating temporal changes in the radar reflectivity at 10 km height and searching for a maximum increase after the first time step of detection (References added in the manuscript). In response, rename "cooling" to "reflectivity gradient" to describe this step more clearly.
Author’s changes in the manuscript: See Sect. 3.6, lines 240-246 for a description how we approximate the development stage of convection by using the radar reflectivity at 10 km height: "Unlike methods that assess cloud stages using a cooling induced by temperature changes, the ML-based radar reflectivity does not provide information on temperatures. As an alternative, we approximate the life-cycle using temporal changes in radar reflectivity at 10 km height and the resulting vertical and horizontal cloud characteristics. For estimating the vertical growth of the cloud, we compute the difference between CTH and CBH (i.e., to display the height of the cloud layer) for every point in time. For the horizontal growth of the cloud, we calculate changes of the cloud area derived as proportional differences to the cloud area at the first timestep of detection." and lines 247-253: "Development stage: Building on the approach by Luo et al. (2008), we use a radar reflectivity threshold of 0 dBZ at 10 km altitude as a proxy for potential cloud-top cooling, which may be indicative of convective growth. We calculate the temporal gradient of radar reflectivity at 10 km for each cloud trajectory, identifying the time of maximum increase to mark the cloud development stage. This stage may be associated with a high cloud vertical layer and strong updrafts that support continued vertical growth (e.g., Kikuchi and Suzuki (2019); Chen et al. (2021)).The transition from development to maturity is defined by the time of maximum radar reflectivity increase (Takahashi et al., 2023; Hu et al., 2021)."

- **Fig. 13**: Fig. 13: this fig is interpreted as providing evidence for differences over land and ocean (L332, L333, L338), but to my eye the land/ocean results are almost identical, e.g. with differences in reflectivity being far smaller than the uncertainty of 3dBz (Table 2). Conclusions about land/sea differences appear unwarranted.
Author’s response: We agree and change the description of the figure to focus on differences between clouds with a single core and multiple cores instead of land-sea differences (which we agree to be more marginal, see e.g., Table 4 of revised manuscript).
Author’s changes in the manuscript: Please see Sect. 4.3.1 for the relationship between life-cycle statistics and core numbers, lines 366-376: "To analyse the cloud life-cycle (as outlined in Section 3.6), we check the point of time when three key events occur in each cloud trajectory: the maximum radar reflectivity gradient at 10

km altitude ("reflectivity gradient"), the maximum cloud area growth("area growth"), and the maximum vertical growth ("vertical growth"). Figure 13 shows the distribution of these indicators grouped by the surface type and number of cores. The average maximum reflectivity gradient ranges from 10 to 16 dBZ. Clouds with 2–3 cores show the highest gradients (14.5–16 dBZ), while the gradient for single-core clouds averages around370 14 dBZ. It decreases with further increasing core count, dropping to around 10 dBZ for clouds with 10 or more cores. Surface type has little impact overall, though values are slightly higher over the ocean for clouds with 1–3 cores (Figure 13, a). In contrast, cloud area growth is slightly higher over land. More important, clouds with multiple cores grow considerably more in area than single-core clouds - ranging from 22 % (single-core) to 52 % (10 and more cores) (Figure 13, b). For the vertical growth, we observe average values between 5–8 km. Single-core clouds tend to grow higher than multi-core clouds, with only minor differences between land and sea (Figure 13, c)."

- **Fig. 14**: Please clarify whether Fig 14 x-axes are cloud lifetime or the time from CI, it is confusing at the moment (e.g. discussion at L340). My best guess is the plot shows a PDF of the times at which x occur, where x is max area growth rate, max number of cores, etc. This is not really lifetime so please reword things. If this is true, how do most clouds have maximum core size at 0 hours? How does max cooling rate most often occur at hour 0 which should by definition have a cooling of 0?
  Author's response: The x-axes refer to the time derived after the first detection of the cloud (which would be the CI). We add a revised version of the figure displaying the PDF of the times each statistic (e.g., max cores, max growth) occurs, grouped by the number of cores to show these timing differences be more clearly.
  Author's changes in the manuscript: See Sect. 4.3.1, lines 390-415 for a revised description of Figure 15.

- **L343**: "Multiple peaks characterise the distribution for single-core clouds" not supported by plot
  Author's response: We agree and revise the description of the figure.
  Author's changes in the manuscript: See above, please find a revised description in lines 390-415.

- **L357**: "We observe a morning peak followed by a decrease in the afternoon ..." not supported by plot
  Author's response: We agree and revise the description of the figure.
  Author's changes in the manuscript: Please see Sect. 4.3.2, lines 416-435 for the description of (now) Figure 16. E.g., lines 416-426: "The reflectivity gradient exhibits short-term fluctuations with noticeable nocturnal peaks around 20:00–21:00 UTC and 00:00–01:00 UTC, followed by decreases. During the day, peaks occur between 09:00–12:00 UTC and around 16:00 UTC, with a negative dip around noon (land) and 18:00 UTC (both land and sea). Over the ocean, the reflectivity gradient is generally higher and shows a slightly weaker variability than over land. Over land, multi-core clouds exhibit stronger gradients than single-core clouds. Distinct land-based negative peaks occur around 03:00–06:00, 08:00, and 11:00–15:00 UTC. Over the ocean, we find a weaker nocturnal peak at 01:00 UTC and a gradual increase between 06:00–20:00 UTC. Overall diurnal variability ranges from 0.5 dBZ (ocean) to 1 dBZ (land), or roughly 8–16 % of the mean gradient range (10–16 dBZ) (Figure 16, a, d)."

- **L360**: "Clouds with a single core show a reflectivity difference of up to 14 dBZ between CI and MAT and a vertical growth of 5.6–7 km. With an increasing number of DCCs, the total cooling and vertical growth of each DCC decreases as prior convective activity already induced a higher average radar reflectivity. In contrast, the anvil growth is on average 15 % higher for clustered systems." unclear where this is shown. Are we still talking about fig 15?
  Author's response: We revise the text in the manuscript.
  Author's changes in the manuscript: See comment above for description of (now) Figure 16 in Sect. 4.3.2, lines 416-435.

- **Sect. 5.1**: I find this section distracting and not well tied to the results found in the present paper. The only clear link seems to be L394, discussing the seasonality which I suggested above should be removed. It comes across as a literature review rather than a review of the new findings.
  Author's response: Thank you for your comment. While we think the section provides additional context to our results, we aim to improve the text to better link our findings with previous studies.
  Author's changes in the manuscript: Please see revised Sect. 5.2, lines 482-515 (e.g., lines 482-489: "Compared to previous studies by Takahashi et al. (2023) and Hu et al. (2021), our analysis identifies a significantly higher number of potentially convective cloud tracks. The derived cloud characteristics align well with aircraft

observations (Zipser and LeMone, 1980) and precipitation-based studies (Zipser et al., 2006). Over tropical Africa, our core distribution results are consistent with those derived for geostationary satellite data (Jones et al., 2024) or the CloudSat CPR Deng et al. (2016), both of which found a high prevalence of clouds with one to three cores. Similarly, Pilewskie and L'Ecuyer (2022) reported that one-third to half of convective systems observed globally by the CloudSat CPR contain a single core. For the tropics, however, our results are in closer agreement. In line with these findings, we observe that cloud area generally increases with the number of cores. However, this relationship exhibits substantial variability, especially in multi-core systems (Section 4.3.1)."

- **L405**: "lacks sensitivity to observe ice" → "weak representation of shallow convection" Are you sure this is what you mean?
  Author's response: We suggest the CloudSat CPR has a limited sensitivity for thin clouds in high altitudes and shallow convection in low altitudes (radar attenuation due to topography). These limitations are reflected by our ML-based 3D predictions. We revise the description in the manuscript.
  Author's changes in the manuscript: Please see Sect. 5.3, lines 516-541 for a revised verison of the limitations, e.g., lines 519-523: "The input data for the ML model are based on observations from the Cloud Profiling Radar (CPR) aboard the CloudSat satellite, which has known limitations in detecting ice clouds due to its tendency to underestimate the height of upper-level outflow (Wang et al., 2014). Additionally, signal attenuation near the surface caused by topography reduces the CPR's sensitivity to shallow convection. As a result, our analysis underrepresents both shallow convective and cirrus cloud types."

- **Section 5.2**: Thank you for including a limitations section (5.2).
  Author's response: Thank you.
  Author's changes in the manuscript: Sect. 5.2 is now Sect. 5.3

- **L431**: "Isolated convective cells have a higher cooling and more extensive vertical growth than clustered clouds." See the above about cooling. This also appears to confuse vertical growth rate with cloud height, at least in how it reads to me. I don't think cloud height was explicitely considered (?) but cloud top height (Fig 7f) and mean core height (Fig d) are both largest for clouds with the largest number of cores.
  Author's response: The sentence refers to findings about the cloud life-cycle derived from Figures 13, 15 and 16. In the revised version of the manuscript, we aim to improve the description of the results.
  Author's changes in the manuscript: For the concluding remarks, please see Sect. 6, lines 543-561 (e.g., lines 549-556: "The results suggest that differences based on the number of cores are higher than the surface-type induced variability. Single-core clouds develop and dissipate on shorter timescales. They have a smaller cloud and core area, and lower CTH and core height than multi-core systems. The longer cloud lifetime of multi-core clouds may be associated to a later occurrence of the maximum number of cores and core area. Between single-core and multi-core clouds, we find considerable differences in the cloud life-cycle statistics regarding the changes in the radar reflectivity at 10 km height, the vertical growth, and the area growth of the cloud. While the former two are higher for clouds with a single core, multi-core cloud clusters with a larger cloud area tend to grow more along the horizontal dimension. The more cores we find, the later the maximum number of cores and the maximum core area occur."

- **L 433**: "[Isolated convective cells] ... show weaker convective activity" seems to be inconsistent with the above comment that they have "higher cooling".. maybe these things need to be more specifically defined
  Author's response: We agree, we revise the text to describe our findings more clear throughout the manuscript.
  Author's changes in the manuscript: See comment above (revised version of concluding remarks in Sect. 6)

- **L204-211, L375-383**: Up to the authors, but in my opinion some sections discussing the advantage of the 3D perspective considered here **(L204-211, L375-383)** seem out of place and repetitive. While true, this discussion belongs in the intro and conclusions.
  Author's response: Thank you for your remark, we agree this part is repetitive and remove it from the discussion.
  Author's changes in the manuscript: Removed from Sect. 3.4 (Extract cloud and core properties) and Sect. 5 (Discussion). The information may be found in Sect. 1, lines 54-62: "Despite decades of research, knowledge of the 3D structure of convective cores remains limited. In the absence of high- resolution, global 3D observational data, our understanding of the relationship between cores and overall cloud evolution relies heavily on 2D observations and simulations. Active and passive sensors contain important vertical or horizontal information,

but are limited in their spatial and temporal coverage (active) or offer only an approximation of the vertical column (passive) (Masunaga and Luo, 2016; Taylor et al., 2017). To address this gap, we apply a machine learning (ML) framework to reconstruct contiguous 3D radar reflectivity fields from 2D satellite data (Brüning et al., 2024). Our goal is to simultaneously capture the horizontal and vertical evolution of convective clouds and their cores. We use imagery from the Meteosat-11 SEVIRI sensor as input to the ML model, which is trained to reconstruct vertical cross sections based on CloudSat Cloud Profiling Radar (CPR) observations. This approach allows us to extrapolate a continuous 3D cloud field between 2.4 and 24 km altitude."

4 Technical corrections

- **L 298**: the sentence " Especially... up to 0.9" seems out of place, also the reference should be fig 10 not fig 9. Also, there are two terms used in this sentence "axes rato" and "eccentricity" and a third in Fig 10's plot label, "Core Roundness". Please standardize
  Author's response: Thank you for your comment, we update the figure labels and change "roundness" to "eccentricity" throughout the text.
  Author's changes in the manuscript: See Sect. 4.2.1, lines 325-333, for a revised description of (now) Figure 11.

- **Fig 10m,n**: can the area ratio not be clipped at .5? it should go to 1 right?
  Author's response: You are right, the scale is 0-1, we add an updated version of the figure in the revised manuscript.
  Author's changes in the manuscript: See Figure 11 i–l with the scale between 0-1 for the area ratio.