Answers to referee #3

This manuscript presents a long-term characterisation of single-layer cloud macrophysical and microphysical properties at the AGORA ACTRIS-CCRES station (2018-2023), with a particular emphasis on the under-sampled western Mediterranean region. A key contribution is the proposed cluster-based algorithm (CBA), designed to treat clouds as volumetric entities (time-height clusters) and thereby reduce physically unrealistic type-to-type correlations that can arise with profile-based approaches. The paper is generally well written, the motivation is clear, and the results should be useful as regional reference statistics for model/satellite evaluation. I have only two main concerns:

1) Several central elements of the CBA rely on empirically determined thresholds (cloud-size criterion and phase/precipitation rules). For example: a cluster is considered a cloud if it has >100 pixels (excluding drizzle/rain), liquid is defined by P(droplets+drizzle)+P(droplets) > 70%, ice by criteria including P(ice) > 90% (or small droplet fraction), and precipitating clouds by >10 "drizzle or rain" pixels. The manuscript notes these were selected after case-study evaluation, which is a reasonable starting point, but the conclusions (cloud-type frequencies and derived property statistics) could be sensitive to these choices.

I would suggest adding a short sensitivity analysis showing how key outputs change when thresholds are perturbed (e.g., cloud pixel criterion 50/100/150; liquid threshold 60/70/80%; precip threshold 5/10/20 pixels). Reporting changes in (a) cloud-type occurrence and (b) a couple of headline statistics (e.g., median LWP/IWP, CBH/CTH or thickness) would greatly strengthen confidence. Alternatively, provide a brief justification table summarising the thresholds, what they control, and why they are physically/observationally motivated.

We thank the reviewer for this suggestion. The sensitivity analysis is now presented in Figure 1, showing the annual variability of cloud occurrence and cloud properties (i.e. CBH, THICK, LWP, IWP) for different tested thresholds. The results obtained with the thresholds used in the manuscript are indicated by dashed lines and square markers as reference value, while the shaded areas show the data range obtained using the minimum and maximum thresholds indicated in the following text, delimited with a narrow and a thick line respectively. The thresholds selected and the observed results for each criteria analyzed are explained next:

1) Cloud pixel criterion: The thresholds are varied in the range 60-140 using a 20 pixel step for the perturbation analysis. A value of 100 was used in the manuscript. No significant changes are observed in cloud frequency, CBH, THICK, LWP, or IWP (see Fig. 1a-e, respectively). The annual patterns remain unchanged, indicating that the results are not sensitive to reasonable variations in cluster size.

2) Liquid fraction criterion: **The threshold is modified in the range 60-90%, assuming a value of 70% in the manuscript as the optimum case. The largest total absolute frequency differences are observed for Liquid/Precipitating-liquid and Mixed/Precipitating-mixed, which are 0.57%/0.61% and 0.57/0.62%, respectively. The monthly differences for each cloud type are shown in Figure 1f. As the threshold increases toward 90%, the frequency of Liquid clouds decreases, while Mixed-phase clouds increase. However, the annual cycle is preserved for all thresholds, and the differences remain within an acceptable range.**

CBH, THICK, and IWP show no significant sensitivity to the liquid threshold (see Fig. 1g, 1h, 1j). Large differences are found for LWP (Fig 1i) in precipitating liquid clouds in January, which is explained by their very low occurrence and high variability during this month. Therefore, a careful consideration of the results is needed in cases where the number of data is low and may be affected by specific conditions (e.g. the Filomena and Gloria storms that introduced large variability in the data analysis during January, as mentioned in the manuscript)

3) Ice fraction criterion

The thresholds are varied in the range 80-100% in steps of 5%, and a value of 90% was used in the manuscript. Frequency differences are observed between Ice and Mixed-phase clouds in Figure 1k. As the threshold increases, the classification obtained leads to fewer Ice clouds and more Mixed clouds. Nevertheless, the annual cycle is consistent across all tested values, and total frequency differences are below 1.5%.

CBH, THICK, and LWP are not significantly affected (see Fig 1l-n). Although IWP (see Fig. 1o) in precipitating ice clouds shows significant differences, the 90% threshold used in the paper yields values very close to those obtained with the strictest criterion (100%), indicating that 90% is sufficiently robust for classifying ice clouds.

4) Rain pixel criterion

The thresholds are varied in the range 80-100% in steps of 5%, and a value of 90% was used in the manuscript. No significant differences are found in cloud frequency or in CBH, THICK, LWP, or IWP (see Fig. 1p-t).

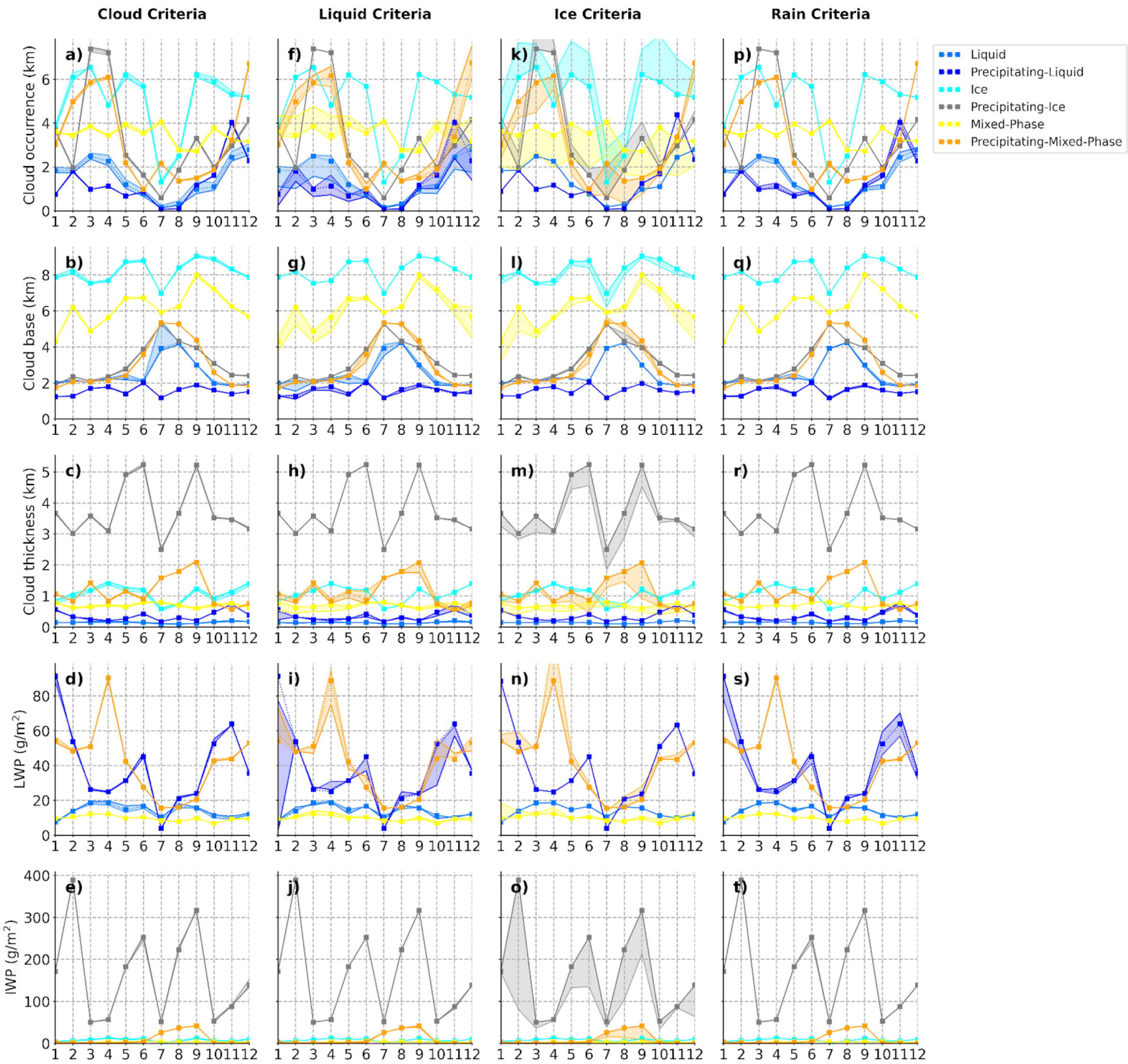

Figure 1. Sensitivity analysis of cloud properties for cloud criteria (a-e), liquid criteria (f-j), ice criteria (k-o), and rain criteria(p-t). For each criteria, cloud occurrence (a, f, k, p), CBH (b, g, l, q), cloud thickness (c, h, m, r), LWP (d, i, n, s) and IWP (e, j, o, t) were analysed for the threshold variations described in the text. Each cloud type is indicated in the legend and Ice clouds are not shown in LWP analysis and liquid clouds are not shown in IWP analysis.

Overall, this sensitivity analysis confirms that the main conclusions of the study are robust to reasonable perturbations of the classification thresholds. Therefore, the presented analysis is included in the revised manuscript in the appendix C.

2) The manuscript clearly documents strong seasonality in data availability, with Jan-Mar having the lowest availability (40-50%), while Apr-Oct exceeds 60%. Missing periods are linked to maintenance/technical issues and scanning measurements not processed by Cloudnet. This is important context because many results emphasise seasonal contrasts, and uneven sampling could bias frequency estimates and vertical-profile statistics.

Can the authors add a short assessment of whether the reported seasonal patterns remain robust after accounting for uneven sampling.

We thank the reviewer for raising this important point. To assess the impact of uneven data availability on the reported seasonal patterns, we analysed the annual cloud type occurrence separately for each year and compared them with the complete period presented in the manuscript (see Fig. 2).

Figure 2 shows the yearly cloud occurrence per month for each cloud type, highlighting the complete period reported in the paper (in black). For liquid/precipitating-liquid clouds, the frequency of occurrence is generally consistent from year to year, as can be seen in Figure 2a-b. The values reported in the manuscript are particularly close to those from 2021 and 2022, which have the most homogeneous monthly data coverage. The largest deviations from the overall median are observed in 2018 and 2023 (blue and brown lines). These deviations are due to a lack of data as can be seen on the revised manuscript in Figure 1, but do not alter the global statistics.

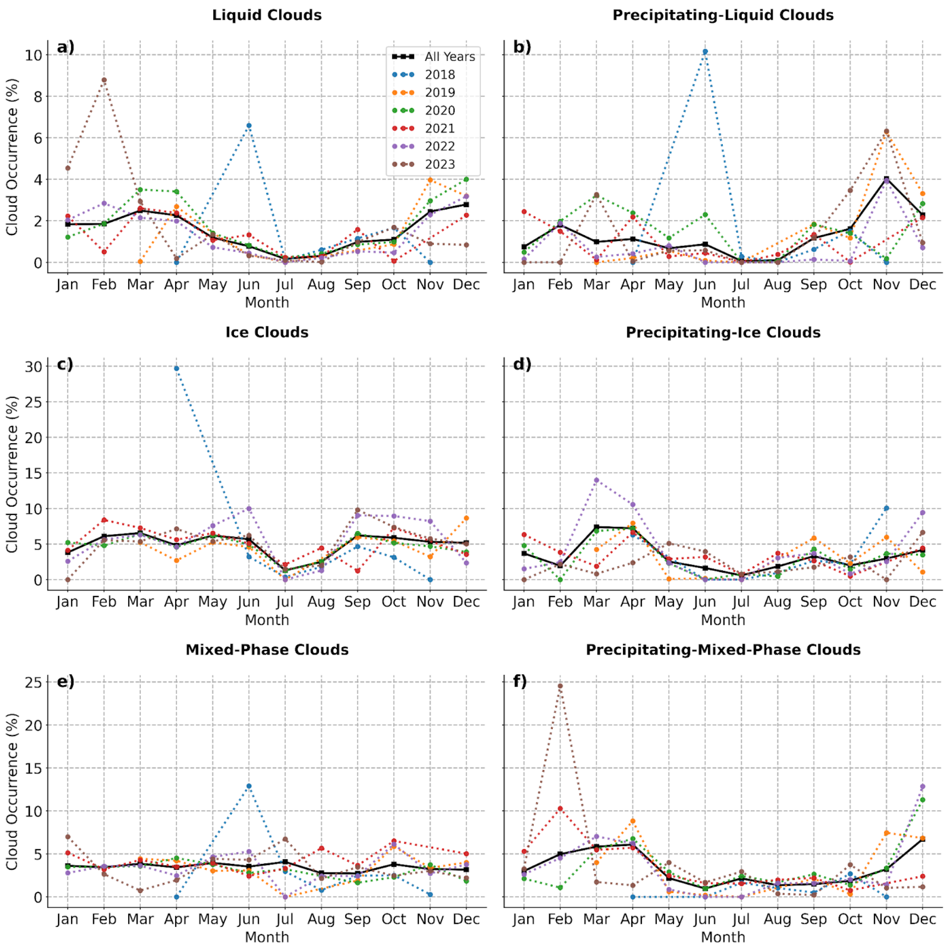

Figure 2. Monthly cloud occurrence for each cloud type. (a) Liquid, (b) Precipitating liquid, (c) ice, (d) precipitating ice, (e) mixed-phase, (f) precipitating mixed-phase clouds. The cloud occurrence computed in the manuscript for the whole period is represented in black, and other years as illustrated in the legend.

The same behaviour is observed for ice/precipitating-ice and mixed-phase/precipitating-mixed-phase clouds. Despite seasonal differences in data availability, the main seasonal contrasts and relative cloud-type frequencies remain robust.

Overall, although large deviations are found between global statistics and particular months of 2018 and 2023, the reported seasonal patterns are in good agreement with other years with more data availability and are not substantially biased by uneven sampling.

Other minor comments:

1. Cloud-top definition is said to be not valid when radar LWP > 0.9 kg m^{-2}, and such cases are filtered because attenuation may mask cloud tops. It would help to report how frequent this condition is and whether it impacts reported cloud thickness distributions.

We thank the reviewer for the suggestion. The attenuation frequency per month for all cloud types is shown in Figure 3. This figure shows very low frequency over the year, with a total attenuation frequency of 1%. It indicates that statistics will likely not be significantly affected by the attenuation filter. We reported these values in the revised manuscript, which now reads in lines 302-303.

> **"…in Cloudnet post-processing and the LWP filter for values exceeding 0.9 kg m^{-2}, which only accounted for 1% of cases, precipitating clouds still exhibit…"**

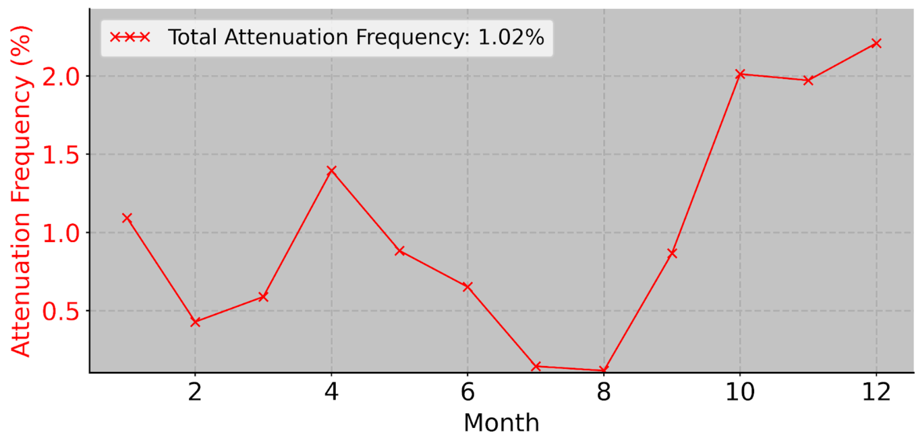

Figure 3. Monthly Frequency of identified strong attenuation cases (LWP > 0.9 kg m^{-2}).

To address the impact of the attenuation filter on cloud thickness statistics, we compared seasonal cloud thickness distributions with and without the filter applied for each cloud type (see Fig. 4). This figure shows the median cloud thickness for each cloud type (solid line) and the interquartile range (shaded area). For Liquid clouds shown in Figure 4a, no differences in median cloud thickness are observed when applying the attenuation filter.

The same behaviour is found for all non-precipitating cloud types (see Fig. 4a,c,e), indicating that strong attenuation does not affect their reported thickness distributions.

For precipitating ice clouds, although the median thickness without filtering is slightly smaller in DJF, JJA, and SON, these differences are within the seasonal variability indicated by the interquartile range and do not significantly affect the statistical analysis. For precipitating liquid clouds, slightly larger median thickness values are found when the filter is removed. Similar to precipitating ice clouds, these differences remain within the overall variability and uncertainty of cloud thickness, where a large intrinsic variability is evident.

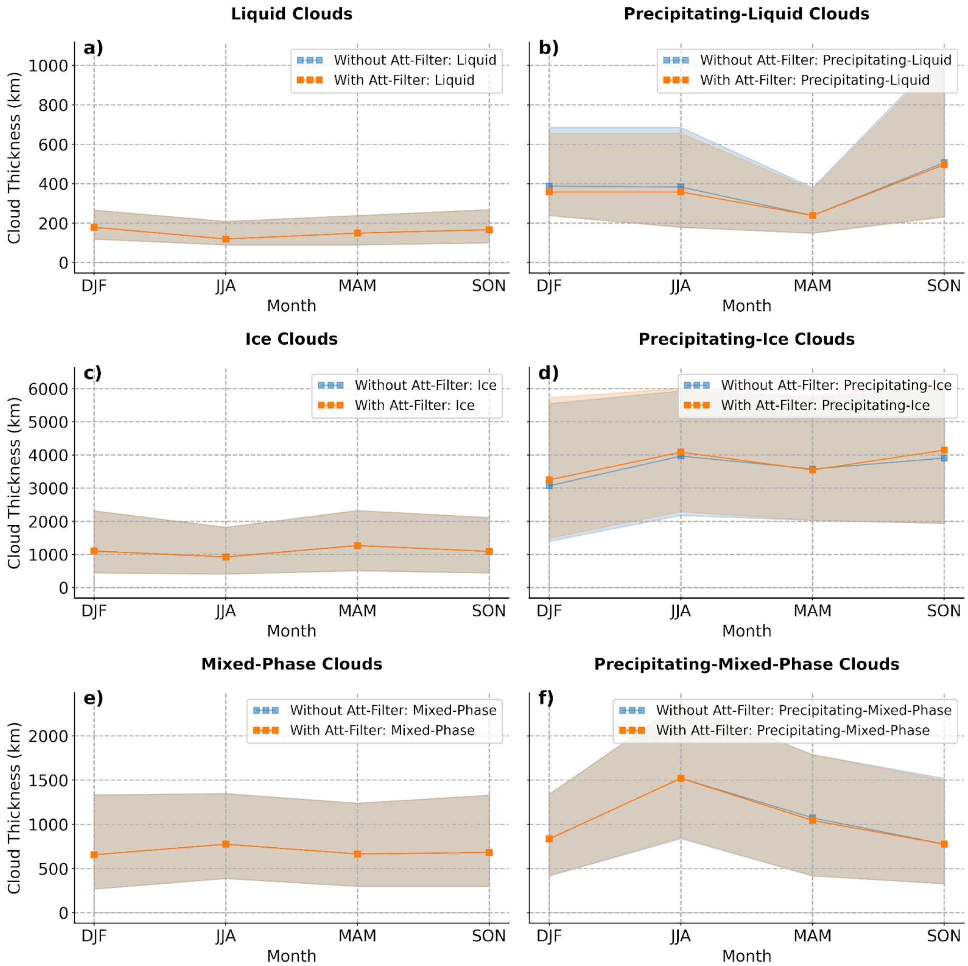

Figure 4. Seasonal median cloud thickness per cloud type. (a) Liquid, (b) Precipitating liquid, (c) ice, (d) precipitating ice, (e) mixed-phase, (f) precipitating mixed-phase clouds. The interquartile range is denoted by the shaded area.

Overall, the attenuation filter has a negligible impact on the reported cloud thickness distributions and does not affect the main conclusions of the study.

2. Ensure consistent terminology between “TCP/TC” and the Cloudnet “target classification” product across sections.

Done