

Answers to referee #1

1 General comments

This manuscript presents a 5-year analysis of cloud statistics at the station AGORA in Granada, Spain, using data of ground-based observations (radar, ceilometer and microwave radiometer). The dataset is analyzed focusing on the microphysical and microphysical properties of single-layer clouds. The authors introduced a cluster-based algorithm which considers cloud volume, and they compared the algorithm with profile-based method used for cloud classification. The dataset presented in this study is the only ground-based cloud database available for this region. The results of this study are valuable for other studies on modeling or comparison with satellites and other the sites with similar ground-based instruments. The manuscript is within the scope of AMT journal. Generally, it is well-structured and well-written manuscript. However, it would benefit from a practical 1 of the proposed method and the inclusion of a case study that demonstrates its performance advantages and potential areas of application. Accordingly, I recommend that the authors undertake a major revision to address the following points.

2 Specific comments

1. The manuscript presents the CBA method, but the question is related to its applicability. What is the applicability of the introduced method CBA with the homogeneous phase of the clouds? What advantages does CBA have over PBA, and in which applications can it be used? The manuscript does not discuss which specific tasks the CBA method is intended to solve. Could authors include a case study which shows the benefit of CBA in one of the applications? Including a case study (or several) that demonstrates when CBA provides new information compared with PBA, and for which applications CBA reduces uncertainty relative to PBA, would substantially strengthen the manuscript.
2. Could the CBA method be forcing the cloud phase and properties to look more uniform than they really are?
3. Questions to Figure 5: How precipitating-ice clouds are derived in the method? What is the difference between Precipitating-Mixed-Phase and precipitating Ice clouds in the applied method? Based on the applied method how do you distinguish between snow and ice cloud particles and therefore separate ice clouds and ice precipitating clouds?
4. In the lines 181-182 the authors wrote: 'For ice and mixed-phase precipitating clouds, it is the first pixels within the melting layer.' If ice clouds have a melting layer, shouldn't they be classified as mixed-phase precipitating clouds rather than as ice clouds?

We thank the reviewer for pointing this out and address the comments as follows:

1) The primary objective of this study is to perform a statistical analysis on cloud properties according to their type, which is inherently dependent on the definition of the cloud and the cloud type. The benefit of CBA is analysed in its terms of mean cloud properties, which is the focus of this manuscript. While exploring its performance in other applications would indeed be interesting, such applications are beyond the scope of this paper. The CBA, based on the Cloudnet target classification, does not aim to introduce new information compared to PBA, but rather to provide an alternative, physically aligned with cloud definition, such as the one reported in Spänkuch et al., 2022, which describes clouds as a collection of visible minute particles (solid, liquid, or both) in the air above the ground. By means of clustering, all the spatio-temporal neighbouring pixels (i.e., cluster) are considered as the same entity (i.e. “radar” visible mass). By using pixels neighbouring in range and in time, clouds are considered as three-dimensional structures. Based on the same approach, Bühl et al., 2016 used a 15-min time interval to identify mixed-phase clouds. Once a cluster is identified, classification as liquid/ice/both is made by weighting cloud phase pixels. Since CBA relies on a range-time characterization, any cloud homogeneity is a result of the way cloud pixels keep together in time and in range, not intrinsically due to the CBA algorithm. In contrast, PBA is strictly limited to individual profiles, leading to short-term phase switching (manuscript example in sec. 3.2) between ice and mixed-phase several times in less than 10 minutes besides it is the same ‘radar’ visible mass. Another constraint of the PBA is its dependence to the zenithal angle: considering the manuscript example in sec. 3.2, off-zenith radar measurements (e.g., 89°, 85°, 80°) would have provided different cloud classifications.

To assess the CBA and PBA performance, Pearson correlation coefficients of daily occurrence, daily average CBH, cloud thickness, and IWP are calculated between ice and mixed-phase clouds for CBA and PBA. The PBA correlations for daily occurrence, CBH, thickness, and IWP averages are 39%, 80%, 84% and 70%, respectively, and for CBA are 8%, 56%, 1.1%, and 1%, respectively. It shows much larger correlations for the PBA, indicating that the CBA can better distinguish different clouds. This is also highlighted in Figure 1 where PBA’s ice and mixed-cloud thickness clearly show the same seasonal pattern (highly correlated). In return, CBA’s ones present different trends with ice cloud thickness minimum in July. This reveals that PBA is enforcing uniformity in cloud thickness opposite to CBA, especially in a region with a marked seasonality in temperature, relative humidity, and aerosol loading (Bedoya-Velásquez et al., 2019; Pérez-Ramírez et al., 2012, Lyamani et al., 2010). These factors are known to influence cloud formation and vertical development, thus different seasonal patterns in cloud thickness are expected, as they are formed through distinct physical processes. Pure ice clouds are formed from direct vapour-to-ice or homogeneous freezing at low temperatures (Lüttmer et al., 2025; Knopf and Alpert, 2023), whereas mixed-phase clouds rely on supercooled liquid plus INP-mediated freezing,

Wegener–Bergeron–Findeisen (WBF) processes and turbulence (Maciel et al., 2024; Mioche et al., 2017; Korolev and Milbrandt, 2022; Huang et al., 2021).

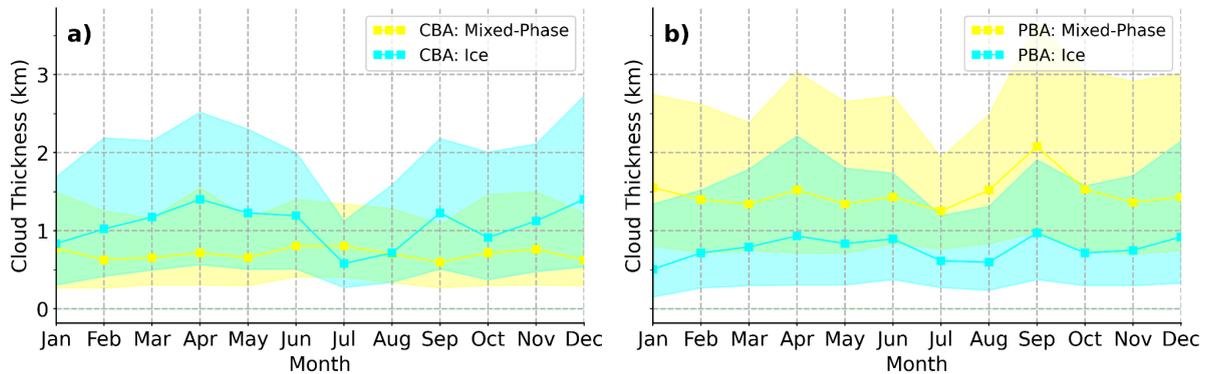


Figure 1. Monthly median cloud thickness for the complete period (2018-2023) comparison for ice (yellow) and mixed-phase (blue) clouds for CBA (a), and for PBA (b). The interquartile range is denoted by the shaded area.

The findings suggest that CBA is a robust and accurate approach for identifying cloud macrophysics properties. Their benefit involves a more distinct separation of physically different clouds based on their average phase. Therefore, the presented analysis was included in section 3.2 in order to strengthen the revised manuscript.

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Spänkuch, D., O. Hellmuth, and U. Görndorf, 2022: What Is a Cloud? Toward a More Precise Definition. *Bull. Amer. Meteor. Soc.*, 103, E1894–E1929, <https://doi.org/10.1175/BAMS-D-21-0032.1>.

Bühl, J., Seifert, P., Myagkov, A., and Ansmann, A.: Measuring ice- and liquid-water properties in mixed-phase cloud layers at the Leipzig Cloudnet station, *Atmos. Chem. Phys.*, 16, 10609–10620, <https://doi.org/10.5194/acp-16-10609-2016>, 2016.

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Mioche, G., Jourdan, O., Delanoë, J., Gourbeyre, C., Febvre, G., Dupuy, R., Monier, M., Szczap, F., Schwarzenboeck, A., and Gayet, J.-F.: Vertical distribution of microphysical properties of Arctic springtime low-level mixed-phase clouds over the Greenland and Norwegian seas, *Atmospheric Chemistry and Physics*, 17, 12 845–12 869, <https://doi.org/10.5194/acp-17-12845-2017>, 2017.

Korolev, A. and Milbrandt, J.: How Are Mixed-Phase Clouds Mixed?, *Geophysical Research Letters*, 49, e2022GL099 578, <https://doi.org/10.1029/2022GL099578>, 2022

Huang, Y., Siems, S. T., and Manton, M. J.: Wintertime In Situ Cloud Microphysical Properties of Mixed-Phase Clouds Over the Southern Ocean, *Journal of Geophysical Research: Atmospheres*, 126, e2021JD034 832, <https://doi.org/10.1029/2021JD034832>, 2021.

2) We agree that the CBA may enforce cloud phases to look more uniform for long-term clusters. However, median duration for liquid/precipitating-liquid clouds is 16.5/30.5 min, for ice/precipitating-ice clouds is 16 min/2 h, and for mixed/precipitating-mixed is 19 min/1 h. Only 5% of all clouds last for more than 4.2 hours (95th percentile), without affecting the statistical analysis. Furthermore, Figure 1 shows significant variation in cloud thickness for CBA, proving that it is not making cloud properties uniform. On the other hand, it's the PBA which can enforce uniformity between different cloud types, exhibiting a similar trend for ice and mixed-phase clouds.

3) Precipitating Mixed-phase clouds are defined following Section 3.1 as clouds that do not meet the liquid or ice criteria and have more than 10 raining pixels at their base. Precipitating Ice clouds are identified by the ice criterion and have more than 10 raining pixels at the cloud base.

For precipitating mixed-phase clouds, the text informs:

On lines 178-179: *“Mixed-phase criteria: If the cluster is not classified as liquid or ice cloud, then it is classified as a mixed-phase cloud”*

On line 180: *“Rain criteria: Clouds with more than 10 pixels of “Drizzle or rain” are classified as precipitating clouds.”*

For precipitating ice clouds, the text informs:

On lines 176-177: *“Ice criteria: Cluster is not classified as a liquid cloud and either “Ice” is greater than 90%, i.e. $P(\text{Ice}) > 90\%$ or the percentage of “Droplets” plus “Ice & droplets” is less than 10%, i.e. $P(\text{Droplets}) + P(\text{Ice \& droplets}) < 10\%$.”*

On line 180: *“Rain criteria: Clouds with more than 10 pixels of “Drizzle or rain” are classified as precipitating clouds.”*

The Cloudnet target classification product, which forms the basis for the clustering and for calculating hydrometeor fractions within each cloud, does not provide an explicit snow category. Consequently, snow and ice particles cannot be distinguished in this analysis. Therefore, in this study, precipitation refers exclusively to liquid precipitation, which is quite accurate since snowfall is not observed at our site. This is now clarified in the manuscript:

On lines 171-173: “...It should be noted that the Cloudnet TCP does not distinguish between snow and ice particles. Therefore, in this study, precipitation refers exclusively to liquid precipitation. This assumption is justified because snowfall is not observed at our site...”.

4) We acknowledge that some studies would classify clouds with a melting layer as Mixed-phase. However, in this work, clouds with more than 90% ice content (or less than 10% supercooled liquid water) are classified as Ice clouds since the contribution of liquid water is quite negligible, with ice properties being strongly predominant.

3 Minor comments (technical corrections)

Lines 86-87: ‘...measures the brightness temperature (TB) around the water vapor (22-31 GHz) and oxygen (51-58 GHz) absorption bands at seven channels for each one,... The main product used here is the liquid water path (LWP) (see Tab. 1), which is derived from the (TB) at the water vapor channels.’ 31.4 GHz is a window channel sensitive to presence of liquid in atmosphere. The frequency range 22-31.4 GHz is sensitive to both water vapor and liquid water absorption. Please correct the sentence.

Thank you for the suggestion, the revised text now reads (on lines 86-88):

“...that measures the brightness temperature (TB) in the 22–31.4 GHz and 51–58 GHz ranges. The first range covers the water-vapor absorption band and a window channel near 31.4 GHz, which is sensitive to liquid water. The second range covers the oxygen absorption band. LWP (see Tab. 1) is mainly retrieved from the 31.4 window and the water-vapor channels...”

Line 82: first time the abbreviation ‘LWP’ appear here. Please add the transcript ‘liquid water path (LWP)’ here and remove from lines 88-89.

Done

Lines 93-94: Please add comma after ‘... respectively, and ...’ : ‘The temporal and vertical resolutions are 15 s and 15 m, respectively, and the full overlap ...’.

Done

Lines 118,119: Please replace 'models' by 'instruments' in the sentence.

Done

Line 137: The abbreviation DCR is not used without transcript and is not explained in the text: '... DCR reflectivity (Z) ... '.

Thanks for catching that. The DCR (Doppler Cloud Radar) is now explained on line 108 of the revised manuscript, and the abbreviation in line 137 is kept.

Line 139: Ice needs to be in double quotes: '...as „Ice“, ... '. Please correct.

Done

Line 165: Please add 'as' in the sentence: '..., it is considered as a cloud... '.

Done

In Figure 3: in part 3b please correct 'CBT' to 'CTH'.

Done

Line 256: please correct to 'the 25/50/75th percentiles'.

Done

Lines 308-309: Please specify exact Figure 7a 'in August (see top-right panel, Figure 7a)'.

Done

Lines 311-312: Please specify exact Figure: 'These peaks do not significantly influence the seasonal statistics, as observed in the seasonal profile (left panel, Figure 7a)'.

Done

Answers to referee #2

The manuscript by Tolentino et al. introduced a new cluster-based algorithm for cloud classification, which reduces spurious correlations found in earlier methods. Great efforts have been devoted to addressing the gap of studies in South of Europe. This study presented a five-year cloud statistical analysis focusing on single-layer clouds, systematically investigating the macro- and micro-physical properties of different phase clouds. The topic is within the scope of Atmospheric Measurement Techniques. The manuscript is well-structured and well-written. However, I have some concerns regarding the validity and reliability of the method proposed. Specific comments are as follows.

Sec 3.2: Here, the authors evaluated the performance of the CBA algorithm by comparison with the PBA algorithm, based on the Pearson correlation coefficients. Only one case is presented. From my perspective, the CBA algorithm tends to preserve the homogeneity of cloud phase or properties, so such variation in the correlation coefficient is predictable. However, is there an issue of over-uniformity? Comparative validation against other products may better illustrate the algorithm's performance and advantages?

Thank you for pointing that out and for the suggestion. To address a proper answer, we have to deepen our definition of cloud and the aim of its cloud classification. First of all, clouds are “an aggregate of visible minute particulate matter (solid, liquid, or mixed) in the atmosphere above ground” (Spänkuch et al., 2022). By means of clustering, all the spatio-temporal neighbouring pixels (i.e., cluster) are considered as the same entity (i.e. “radar” visible mass). By using pixels neighbouring in range and in time, clouds are considered as three-dimensional structures. Based on the same approach, Bühl et al., 2016 used a 15-min time interval to identify mixed-phase clouds. Once a cluster is identified, classification as liquid/ice/both is made by weighting cloud phase pixels. Since CBA relies on a range-time characterization, any cloud homogeneity is a result of the way cloud pixels keep together in time and in range, not intrinsically due to the CBA algorithm. In contrast, PBA is strictly limited to individual profiles, leading to short-term phase switching between ice and mixed-phase several times in less than 10 minutes despite being the same “radar” visible mass (example in sec. 3.2 of the manuscript) . Another constraint of the PBA is its dependence on the zenith angle: considering the example in sec. 3.2, off-zenith radar measurements (e.g., 89°, 85°, 80°) would have provided different cloud classifications.

Regarding the over-uniformity produced by the CBA, we agree that it may be found for long-term clusters. However, median duration for liquid/precipitating-liquid clouds is 16.5/30.5 min, for ice/precipitating-ice clouds is 16 min/2 h, and for mixed/precipitating-mixed is 19 min/1 h. Only 5% of all clouds persist for more than 4.2 hours (95th percentile), therefore, their impact on the statistical analysis is considered negligible.

To assess the CBA and PBA performance, Pearson correlation coefficients of daily occurrence, daily average CBH, cloud thickness, and IWP are calculated between ice and mixed-phase clouds for CBA and PBA. The PBA correlations for daily occurrence, CBH, thickness, and IWP averages are 39%, 80%, 84% and 70%, respectively, and for CBA are 8%, 56%, 1.1%, and 1%, respectively. It shows much larger correlations for the PBA, indicating that the CBA can better distinguish cloud patterns. This is also highlighted in Figure 1 where PBA's ice and mixed-cloud thickness clearly show the same seasonal pattern (highly correlated). In return, CBA's ones present different trends with ice cloud thickness minimum in July. This reveals that PBA may enforce uniformity in cloud thickness opposite to CBA, especially in a region with a marked seasonality in temperature, relative humidity, and aerosol loading (Bedoya-Velásquez et al., 2019; Pérez-Ramírez et al., 2012, Lyamani et al., 2010). These factors are known to influence cloud formation and vertical development, thus different seasonal patterns in cloud thickness are expected, as they are formed through distinct physical processes. Pure ice clouds are formed from direct vapour-to-ice or homogeneous freezing at low temperatures (Lüttmer et al., 2025; Knopf and Alpert, 2023), whereas mixed-phase clouds rely on supercooled liquid plus INP-mediated freezing, Wegener–Bergeron–Findeisen (WBF) processes and turbulence (Maciel et al., 2024; Mioche et al., 2017; Korolev and Milbrandt, 2022; Huang et al., 2021).

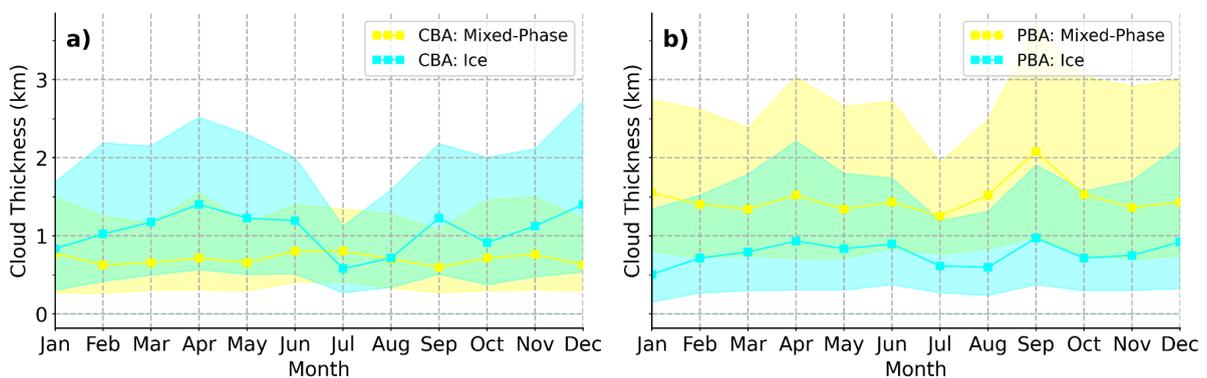


Figure 1. Monthly median cloud thickness for the complete period (2018-2023) comparison for ice (yellow) and mixed-phase (blue) clouds for CBA (a), and for PBA (b). The interquartile range is denoted by the shaded area.

These results indicate that CBA is a robust and accurate method for determining cloud macrophysics. While validation against independent products could further illustrate the advantages and disadvantages of both methods. The comparison analysis presented here demonstrates that CBA provides a quite coherent cloud-phase representation without suppressing cloud variability. Therefore, considering the concerns addressed by the reviewers, the presented analysis is included in section 3.2 in order to strengthen the revised manuscript.

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Spänkuch, D., O. Hellmuth, and U. Görndorf, 2022: What Is a Cloud? Toward a More Precise Definition. *Bull. Amer. Meteor. Soc.*, 103, E1894–E1929, <https://doi.org/10.1175/BAMS-D-21-0032.1>.

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Pérez-Ramírez, D., Lyamani, H., Olmo, F. J., Whiteman, D. N., and Alados-Arboledas, L.: Columnar aerosol properties from sun-and-star photometry: statistical comparisons and day-to-night dynamic, *Atmos. Chem. Phys.*, 12, 9719–9738, <https://doi.org/10.5194/acp-12-9719-2012>, 2012.

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Maciel, F. V., Diao, M., and Yang, C. A.: Partition between supercooled liquid droplets and ice crystals in mixed-phase clouds based airborne in situ observations, *Atmospheric Measurement Techniques*, 17, 4843–4861, <https://doi.org/10.5194/amt-17-4843-2024>, 2024.

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Korolev, A. and Milbrandt, J.: How Are Mixed-Phase Clouds Mixed?, *Geophysical Research Letters*, 49, e2022GL099 578, <https://doi.org/10.1029/2022GL099578>, 2022

Huang, Y., Siems, S. T., and Manton, M. J.: Wintertime In Situ Cloud Microphysical Properties of Mixed-Phase Clouds Over the Southern Ocean, *Journal of Geophysical Research: Atmospheres*, 126, e2021JD034 832, <https://doi.org/10.1029/2021JD034832>, 2021.

Figure 5: “the number of occurrence of a particular cloud, divided by the total number of observations at each month”. According to the definition given by the authors, the sum of Frequency of Occurrence for all conditions (i.e., Single-layer clouds, Multi-layer clouds, Clear-sky, and Not classified) should be 100%, yet the results presented in this figure do not appear to match this expectation. Could the authors clarify this discrepancy? From Figure 5b, could the authors explain the reason for the high occurrence of “precipitating-ice” in Mar and Apr?

Thank you for pointing that out. We double check the data and the sum of the frequencies of occurrence adds to 100% as expected. Regarding the relatively high occurrence of Precipitating Ice clouds in March and April (Figure 5b), a detailed physical interpretation of the seasonal drivers of this feature is beyond the scope of the present study, which focuses on cloud classification and statistics.

Line 35: “asses” change to “assess”

Done

Line 94: “More details can be found in (Cazorla et al., 2017).” Please correct.

Done

Line 188: What’s the definition of “cloud overlap” here?

Done

Figure 3: The “CBT” in part 3) of this figure should be “CTH”. Please correct.

Done

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 $P(\text{droplets}+\text{drizzle})+P(\text{droplets}) > 70\%$, ice by criteria including $P(\text{ice}) > 90\%$ (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).

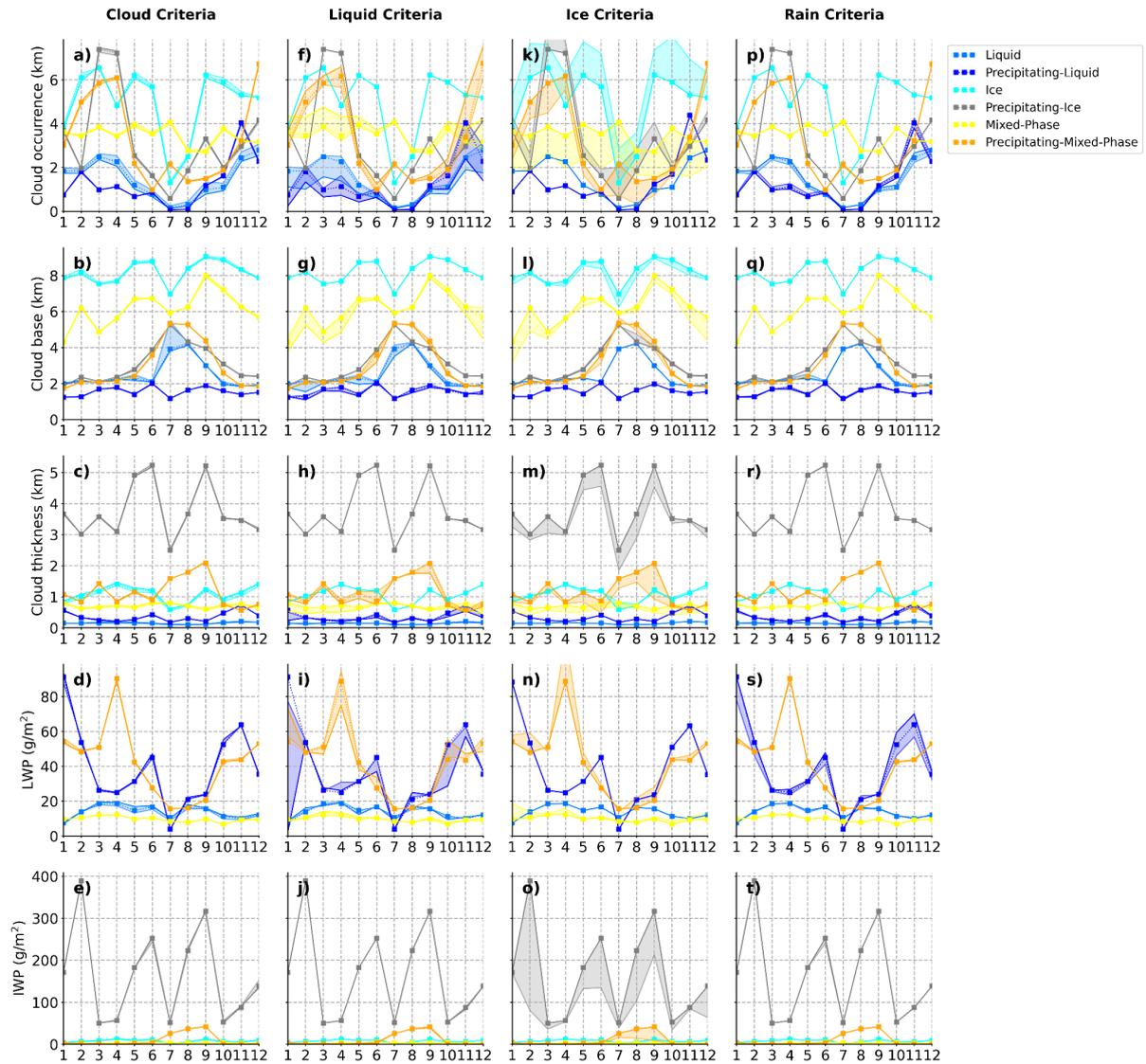


Figure 1. Sensitivity analysis of cloud properties for cloud criteria (a-e), liquid criteria (f-j), ice criteria (k-o), and rain criteria (p-t). For each criteria, cloud occurrence (a, f, k, p), CBH (b, g, l, q), cloud thickness (c, h, m, r), LWP (d, i, n, s) and IWP (e, j, o, t) were analysed for the 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.

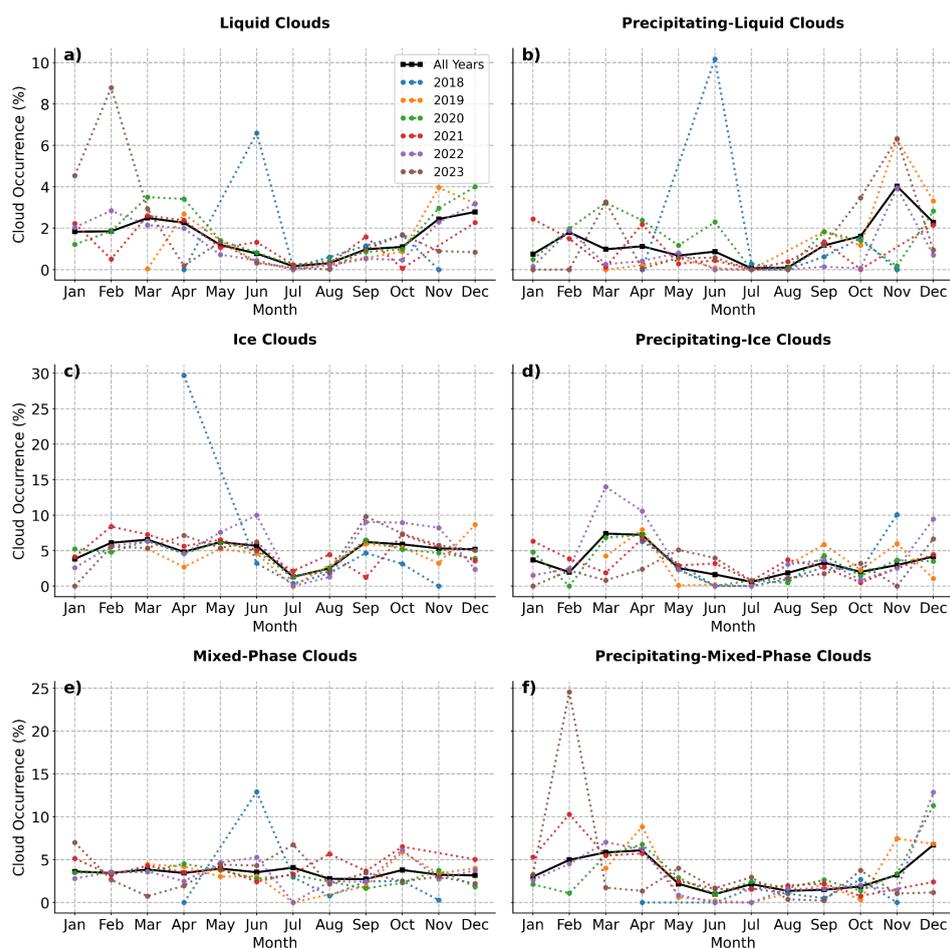


Figure 2. Monthly cloud occurrence for each cloud type. (a) Liquid, (b) Precipitating liquid, (c) ice, (d) precipitating ice, (e) mixed-phase, (f) precipitating mixed-phase clouds. The cloud occurrence computed in the manuscript for the whole period is represented in black, and other years as illustrated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

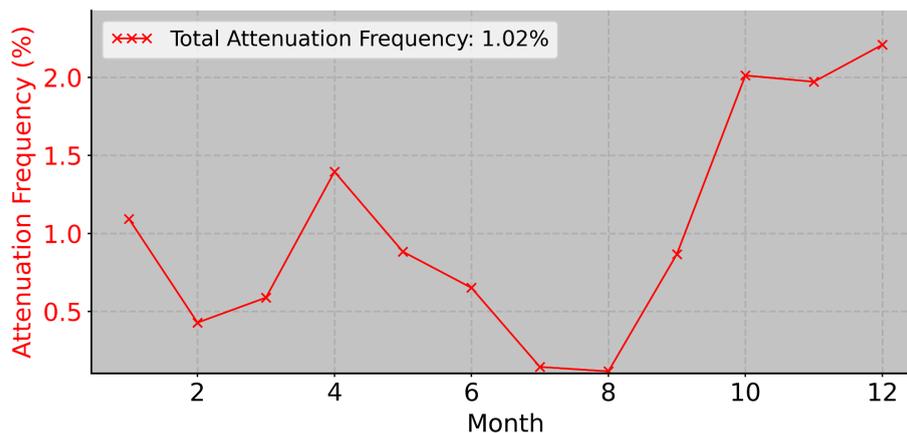


Figure 3. Monthly Frequency of identified strong attenuation cases (LWP > 0.9 kg m⁻²).

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.

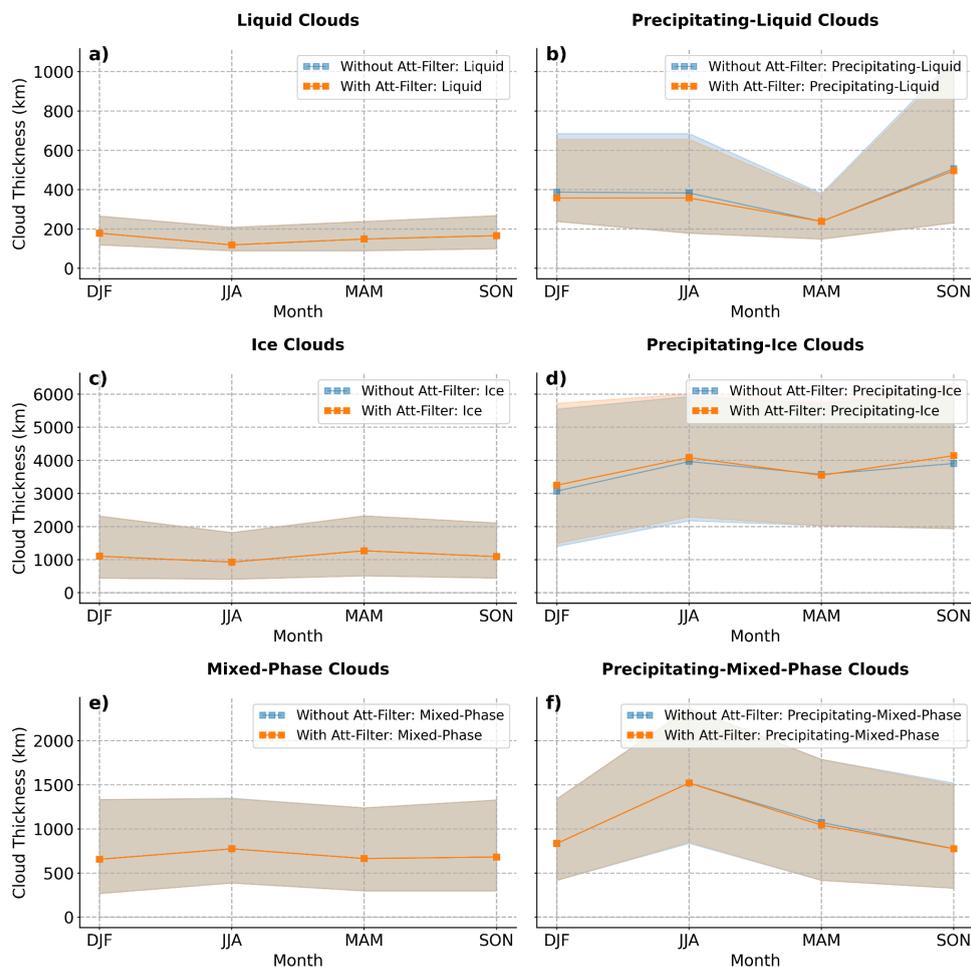


Figure 4. Seasonal median cloud thickness per cloud type. (a) Liquid, (b) Precipitating liquid, (c) ice, (d) precipitating ice, (e) mixed-phase, (f) precipitating mixed-phase clouds. The interquartile range is denoted by the shaded area.

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

