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 zenital angle: considering the manuscript example in sec. 3.2, off-zenith radar measurements (e.g., 89º, 85º, 80º) 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).

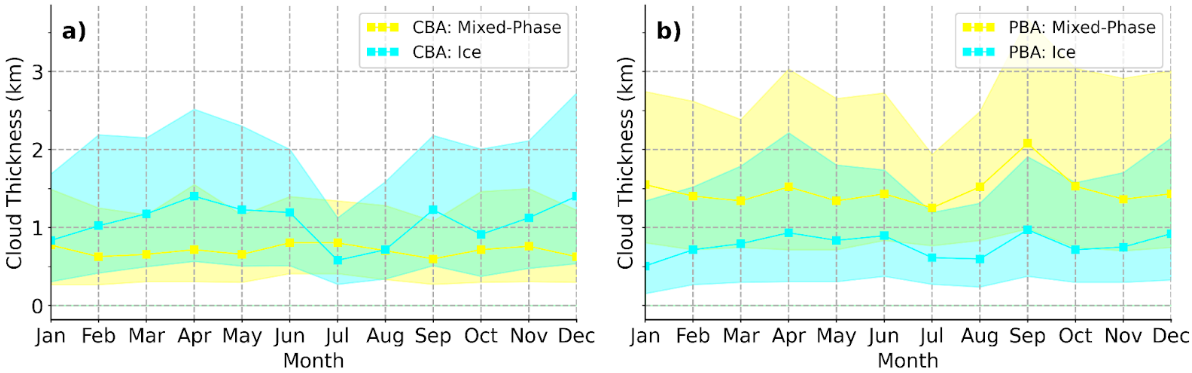

Figure 1. Monthly median cloud thickness for the complete period (2018-2023) comparison for ice (yellow) and mixed-phase (blue) clouds for CBA (a), and for PBA (b). The interquartile range is denoted by the shaded area.

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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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(Ice) > 90% or the percentage of "Droplets" plus "Ice & droplets" is less than 10%, i.e P(Droplets) + P(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