

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).

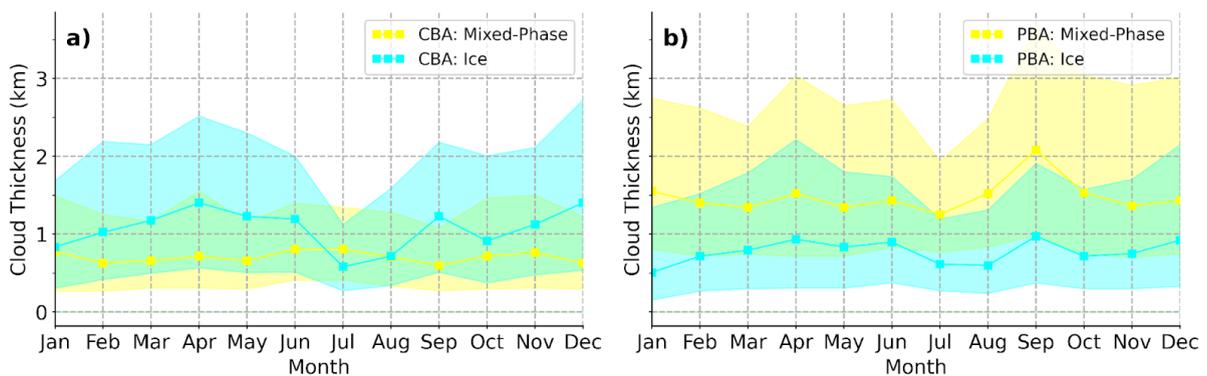


Figure 1. Monthly median cloud thickness for the complete period (2018-2023) comparison for ice (yellow) and mixed-phase (blue) clouds for CBA (a), and for PBA (b). The interquartile range is denoted by the shaded area.

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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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”

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

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

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

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