Community comment on

“A Threshold-Based Method for Cloud Base Height Detection using Ceilometers: Application to Long-term observations in deriving Cloud Vertical Structure”

I appreciate the authors' efforts in presenting this study (https://doi.org/10.5194/egusphere-2026-3317) and agree that the topic is relevant for the AMT readership. However, after reading the preprint, I have several concerns regarding the methodology, comparison data and the interpretation of the results. In my view, the following issues should be addressed before the conclusions can be considered sufficiently supported.

Major comment 1 – Assets

In the section *“Code and data availability”* (p. 25) the authors note that both the code and the data will soon be made available in a public repository. This should be done as soon as possible and is essential to clarify which CL51 data were used for the cloud base height (CBH) – as set out in Major comment 2. In addition, this should make it possible to verify the actual origin of the satellite-based CBHs (see Major comment 4).

Major comment 2 – CL51 cloud base heights

In Sect. 2.3.4., the authors describe the manufacturer’s algorithm for CBH detection in the CL51, specifically the Sky Condition Algorithm (SCA). However, the Vaisala CL51 provides instantaneous cloud base detections (“cloud hits”) independently of the SCA.

The CL51 cloud detection algorithm is applied to a single backscatter profile (typically every 16 s but depending on output configuration) and searches for significant increases in backscatter that meet its cloud detection criteria kept secret. According to the instrument documentation (Vaisala, 2026a) the backscatter profile is processed and cloud bases are detected directly, with up to three CBHs reported simultaneously.

The CL51 SCA is documented by Vaisala (2026b) and is used, for example, in the study by Šálek et al. (2019). It takes those cloud hits accumulated over time (moving 30 min, where latest 10 min weighted twice) and determines the heights and cloud cover of at most five layers. The Combine module is the stage that converts the many cloud clusters produced by the Clusterize module into a smaller set of candidate cloud layers. Rather than simply merging adjacent clusters, it performs a moving-window search for the altitude ranges that contain the greatest cloud cover. The key idea is not clustering cloud hits – that has already been done. Instead, it is aggregating nearby clusters into meteorologically meaningful cloud layers by maximizing total cloud cover within an adaptive vertical window. This produces a concise list of candidate layers, which the subsequent Select module then refines (rounding heights, merging very close layers, assigning high-cloud cover, and limiting the output to at most five reported layers).

I encourage the authors to clarify which CBHs they used from the CL51. The comparison with the proposed threshold-based detection (TBD) method must be based on the cloud hits.

Major comment 3 – TBD method

As discussed and demonstrated by Van Tricht et al. (2014), the choice of the backscatter coefficient threshold for determining the CBH depends on the specific application. Under Arctic conditions with low aerosol loading, they found an optimal value of $3 \cdot 10^{-7}\mathrm{m}^{-1}\mathrm{sr}^{-1}$ for the attenuated backscatter coefficient (β_{att}). According to ISO 28902-4 (2026), particularly Tables 1 and 5, the threshold range of β_{att} is $2 \cdot 10^{-4}\mathrm{m}^{-1}\mathrm{sr}^{-1} \pm 15$ % ($1.7 \cdot 10^{-4}\mathrm{m}^{-1}\mathrm{sr}^{-1} \ldots 2.3 \cdot 10^{-4}\mathrm{m}^{-1}\mathrm{sr}^{-1}$) for water clouds below 10,000 ft (3,048 m). In Sect. 2.3.5, the authors must comprehensibly explain how they determined their threshold value of $1 \cdot 10^{-5}\mathrm{m}^{-1}\mathrm{sr}^{-1}$ and how it can be justified.

The proposed TBD method requires a cloud layer thickness of at least 50 m, which corresponds to 5 range bins at a vertical resolution of 10 m. This value is arbitrary and certainly not universally applicable. A cloud layer can be only a few meters thick and still be considered a cloud. This is common for shallow lifting fog, thin stratus, or small patches of cumulus. Van Tricht et al. (2014) increased their minimum cloud thickness from 50 m to 90 m during the AMT interactive discussion stage (www.atmos-meas-tech-discuss.net/6/C4550/2014/). Is it a coincidence that your value is also 50 m?

The requirement that the CBH must be consistently detected in at least four consecutive profiles within the range of $t \pm 2$ cannot be applied to real-time measurements, as future time steps are unknown.

I wonder whether the independent precipitation measurements from the KCON's automatic weather station (e.g., supplementary Fig. S1) were used to formulate points 5 and 6 in Sect. 2.3.5. The authors claim that a cloud thickness of more than 1.5 km clearly indicates a precipitation event and exclude the corresponding backscatter profiles. First, their *"visual inspection of several representative cases"* is subjective and difficult to follow. Second, this criterion can be considered a necessary but not sufficient condition for many precipitation events. Third, modern ceilometers can reliably detect CBHs during feeble and moderate rain. Only during obscuration conditions (e.g., heavy rain) a vertical visibility (VV) hit may be reported by the ceilometer. Even a CBH with greater uncertainty during precipitation is better than no value, because otherwise the cloud amount would be systematically underestimated.

The fact that most near-surface fog layers over the Indo-Gangetic Plain form within the 0 m to 200 m altitude range (lines 264-265) by no means justifies simply ignoring all ceilometer cloud detections up to 200 m. How do the authors intend to capture, for example, rising fog or low-level stratus clouds? At this point at the latest, the TBD method is no longer generally applicable.

Major comment 4 – Comparison with satellite data

In Sect. 2.3.6, the authors refer to the dataset "CAL_LID_L1-Standard-V5-00". This CALIOP Level 1B data product contains a half orbit (day or night) of calibrated and geolocated single-shot lidar profiles, including 532 nm and 1064 nm attenuated backscatter and depolarization ratio at 532 nm. Cloud characteristics such as cloud top height (CTH), CBH, and vertical structure (cloud layers) are derived from Level 1 data and provided in Level 2 products like "CAL_LID_L2_01kmCLay-Standard-V5-00". As mentioned in Major comment 1, it is unclear where the CALIOP value of 2837 m for the CBH from the satellite flyover on 09 August 2020 comes from. The corresponding CBH value is missing for the CALIPSO flyover on 21 March 2023, both in the text and in the supplementary Fig. S10.

Previous comparisons between CALIOP and ground-based ceilometer or lidar observations (e.g., Dupont et al., 2010) indicate that CBHs agree within a few hundred meters under suitable observing conditions, although larger discrepancies occur owing to sampling differences, horizontal distance, cloud heterogeneity, and attenuation effects. Kim et al. (2011) concluded that CALIOP provides reliable CBHs for thin high-altitude cirrus clouds containing small-sized ice particles, but the cloud profiling radar (CPR) onboard CloudSat has low sensitivity to these clouds due to the use of different wavelengths, 532 nm and ~3.2 mm (94 GHz), respectively. Further, for multilayer clouds CALIOP has difficulties in determining the cloud vertical structure for thick clouds underlying thin cirrus clouds due to the signal attenuations, whereas the CPR detects the CTH and CBH of both the cloud layers.

The current comparison – with two very brief (about 8 s) CALIPSO flyovers and with just one equally brief flyover by the CPR onboard of EarthCARE on 21 June 2024 – is not meaningful enough and is not convincing. While CALIOP can detect CTH with relatively high reliability, the same is true for a ceilometer with regard to CBH. However, the derived cloud thickness – which is based on different assumptions – is generally more of an estimate. In case of Kolkata, a CALIPSO flyover that comes close may still be 10 – 50 km away, depending on the orbit. The detection of the cloud layers by CL51 was undoubtedly carried out simultaneously, but at a considerable horizontal distance. The CALIOP comparison serves merely as a baseline test, but it is by no means an evaluation that proves the TBD method produces "better" CBHs than the internal CL51 algorithm.

The authors' statement (line 308) – *"A detailed study on inter-comparison will be taken up as a separate study."* – is unacceptable. It must be part of this article, as this is of fundamental importance to assess the suitability, robustness, quality, accuracy and added value of the proposed TBD method. In addition, the authors should discuss in more details the strengths and weaknesses of the comparison data used (different wavelength, satellite-based vs. surface-based, etc.) and specify any errors or uncertainties in order to better quantify the quality of the internal CL51 algorithm and the TBD method. I am aware of the difficulty of finding a suitable reference dataset.

Even if CALIOP can detect CBHs in multilayer situations, Mülmenstädt et al. (2018) developed a technique to estimate the CBH of the lowest cloud in each column. Using ground-based ceilometer data the predicted CBHs and their uncertainty were found to be biased by less than 10 %. This dataset is freely available under https://doi.org/10.1594/WDCC/CBASE at "Deutsches Klimarechenzentrum" (DKRZ). Unfortunately, it only covers the years 2007 and 2008. Since both the source code for the Cloud Base Altitude Spatial Extrapolator (CBASE) algorithm is available and the CALIOP Vertical Feature Mask (VFM) can be downloaded as input data through 30 June 2023, the dataset could be expanded. I highly recommend it for the comparison with CL51 since this reference dataset would be a better "ground truth" for CBH.

Major comment 5 – Interpretation and conclusions

The present study proposes a TBD method with a new threshold value for β_{att} and application of subsequent plausibility criteria. However, it is essentially an adaptation to their specific use case and the shortcomings of the CL51 – neither of which is universally applicable. The actual main problem is that there is no universally valid and accepted definition of the CBH or of a cloud in general (e.g., Spänkuch et al., 2022; ISO 28902-4, 2026).

The authors concluded that the internal CL51 algorithm: A) *"… detects multiple cloud-base heights within the same physical cloud layer (Fig. 5)"*. This could simply be a bug in the CL51 SCA (see Major comment 2) that causes the clusters associated with CBH1 and CBH2 not to be merged correctly. The clustering of the "cloud hits" itself can lead to a single physical cloud layer being erroneously split into two.; B) *"… produces ambiguous CBH estimates during precipitation events …"* This should not be the case with feeble to moderate rain (see Major comment 3) and is perhaps a bug or artifact of the CL51.; C) *"… sometimes reports very low CBH values that are more likely associated with fog layers …"* This is a conjecture and needs to be verified with independent measurements. In conditions of visually dense fog, the CL51 should ideally report a VV hit rather than a CBH hit.

How does the TBD method perform with very low clouds having CBHs of less than 1,000 ft (ca. 300 m) when all CBHs below 200 m are generally disregarded (see Major comment 3)? The conclusion that the TBD method leads to *"a clear improvement in CBH detection"* is not sufficiently supported by the presented results – such as the comparison with satellite-based measurements (see Major comment 4). Even though the TBD method is technically applicable to other ceilometer data, it does not necessarily lead to a general improvement for every location like Munich (Fig. 8) or Lindenberg (Fig. S13).

The authors attempt to quantify the differences in CBH between the internal CL51 algorithm and the TBD method by comparing the respective differences (CBH2 – CBH1) between the second and first reported cloud layers. Figure 9 shows monthly mean differences using consecutive CBH detections. This procedure raises doubts: A) CBHs recorded by the CL51 below 200 m and during precipitation are intentionally excluded from the TBD method and are therefore not accounted for in the analysis.; B) If the lower cloud layer dissipates between time t and $t+1$, then CBH2 at time t corresponds approximately to CBH1 at time $t+1$. If an additional cloud layer appears between two existing ones at time $t+1$, then CBH2 at time t roughly corresponds to CBH3 at time $t+1$. The difference (CBH2 – CBH1) for consecutive time steps therefore does not always consider the corresponding cloud clusters.; C) Calculating a mean value (hourly or monthly) does not correct A) and B).

Significant deviations from the CL51 are inevitable, as the TBD method deliberately disregards precipitation events and CBHs below 200 m. The calculation of a normalized cloud occurrence cannot improve this apples-to-pears comparison. Why don't the authors also remove the respective events from the CL51 data?

Overall, are you confident that your conclusions regarding the CL51's performance can be generalized to other ceilometers, even those from other manufacturers? Deficiencies in CBH detection are attributable not only to the internal algorithm but also to the optics and components used. I recommend examining the individual backscatter profiles. Figure 9 in Wagner et al. (2024) suggests that the CL51 can exhibit a β_{att}-profile that is atypical of a single cloud layer, potentially leading to very small separations between CBH1 and CBH2.

Minor comments

- **Lines 11 – 12**: *"Although these algorithms …"* In aviation, guidelines, requirements, and restrictions, for example from the International Civil Aviation Organization (ICAO), European Union Aviation Safety Agency (EASA), Federal Aviation Administration (FAA) or Civil Aviation Authority (CAA), are far stricter than for scientific studies. Nevertheless, the development and improvement of any ceilometer firmware is definitely not restricted to aviation.
- **Lines 65 – 66**: *"The cloud base is generally identified …"* This is only one possible definition of the CBH, not a general one (see Major comment 5).
- **Lines 97 – 98**: *"Standard CBH detection algorithms are primarily designed …"* That is not quite correct! Ceilometer manufacturers certainly aim for CBH detection to work under all weather conditions. Any threshold approach is usually combined with gradient analysis. The CHM15k preprocesses the backscatter profile using altitude-dependent averaging to improve the signal-to-noise ratio, after which cloud features are identified from the averaged profile using backscatter thresholding and gradient-based boundary detection (OTT HydroMet, 2022). The CS136 (SkyVUE8) essentially requires a sufficiently steep increase in the slope of the extinction profile and applies an extinction threshold corresponding to a meteorological optical range (MOR) of 1,000 m (Campbell, 2018). Weaknesses in the manufacturers' algorithms were gradually addressed – sometimes following consultation – and the firmware was improved. The CHM15k, for instance, detects cirrus clouds quite well, but exhibited weaknesses regarding low-level clouds prior to firmware version 0747.
- **Lines 485 – 487**: *"… manufacturer-provided proprietary algorithms, which are primarily optimized for aviation applications …"* Why should modern ceilometers not be suitable for climatological studies? A firmware upgrade or a ceilometer replacement often affects a time series more than a consistent bug.

Summary

The present study addresses an interesting and important problem and has the potential to make a valuable contribution. In my view, however, the current version does not yet provide sufficient methodological detail, and several of its central conclusions are not fully supported by the evidence presented. Addressing the points discussed above would substantially strengthen the manuscript.

Author's note

For transparency, I would like to disclose that I have been working with ceilometers from various manufacturers and of different types for almost 10 years. I coordinate the Ceilometer Working Group at the Deutscher Wetterdienst (DWD) and am the system owner of the autoCLD software component, which uses ceilometer observations to automatically determine the representative CBH and VV values reported in automated airport weather reports such as METARs.

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