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Comment on acp-2020-1252

Anonymous Referee #1

Referee comment on "Satellite retrieval of cloud base height and geometric thickness of low-level cloud based on CALIPSO" by Xin Lu et al., Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-1252-RC1, 2021

General comments

Lu et al. present a novel algorithm to infer cloud base height from satellite-based observations, namely from CALIOP on CALIPSO. This is motivated because existing approaches suffer from high uncertainties which complicate their applicability for certain applications, such as studying cloud-aerosol interactions, determining cloud subadiabaticity, downwelling long wave radiation at the surface, etc. Therefore, the manuscript addresses an important issue.

The VFM, an operational product derived from CALIOP observations, is used as starting point for the CBH retrieval. For a cloud scene which comprises a distance of about 100km, vertical profiles are filtered according to some requirements and the minimum heights (Hmin) of liquid water cloud features are extracted. By taking the 10^{th} percentile of Hmin, the CBH for is determined for this distance. The algorithm is only applied if further conditions are fulfilled regarding the fraction of multi-layer clouds, cloud cover fraction and detection efficiency for each scene. The percentile, along with these scene characteristics are evaluated according to a comparison with ground-based CBH measurements. Ceilometer observations from two island stations in the North Atlantic are utilized as ground-based reference.

The idea for this new approach seems to be inspired by Mülmenstädt et al. (2018) and Böhm et al. (2019). However, the authors should state this more clearly, addressing the similarities. In particular, the algorithm derived by Mülmenstädt et al. (2018) should be described in more detail with the goal to clearly distinguish the proposed algorithm from the former one and to state where the idea comes from and what has been adopted.

The main difference to the approach by Mülmenstädt et al. appears to be the way the cloud base height is derived for a specific point/area. Mülmenstädt et al. take the mean of

all considered VFM CBH retrievals within a distance of 100km weighted by estimated uncertainties to determine the CBH at a given point of interest. Lu et al. use the 10th percentile of all retrievals within a similar area to calculate the CBH representative for the whole area. How these differences might lead to a better agreement with the reference data should be discussed in detail. Another difference between these two approaches is the validation. While Mülmenstädt et al. use METAR reports (ceilometer heights) from about 1500 stations across the continental USA, Lu et al. use two maritime sites (islands in the North Atlantic).

The manuscript is generally well written and nicely structured. However, more details regarding the utilized data should be provided as indicated in the specific comments. Furthermore, I see three major issues with the provided study.

- Only two maritime reference sites are not convincing proof for the applicability of the algorithm on a global scale.
- The development of the algorithm should be improved.
- The validation (Section 4) should be carried out for an independent data set which has not been applied already to develop the algorithm

Regarding 1) Representativeness

The validation is only carried out over maritime regions and includes very few coincident satellite- and ground-based observations (after filtering 72 events remain). Mülmenstädt et al. (2018) argue that various cloud morphologies are represented in their continental validation data set but maritime stratocumulus might be underrepresented hinting that their algorithm might have trouble for this cloud type. Analogous, the problem for this study is the opposite featuring mainly maritime cumulus and stratocumulus clouds. From Figure 8 it becomes clear that the algorithm was developed and validated based on clouds with CBH mostly between 400 and 800m. Therefore, before it can be applied outside this range, in particular over land where apparently higher CBHs dominate, a thorough discussion should be provided on the representativeness of the validation. This would necessitate including continental sites as ground-based reference.

Regarding 2) Algorithm development

So far, the algorithm development (Section 3) comprises mainly the estimation of the following parameters: a suitable quantile to apply to the Hmin distribution; thresholds for Fmulti, Fcloud, Elidar. Furthermore, the VFM quality assurance (QA) flag could be considered (see Mülmenstädt et al., 2018)

Instead of testing out some example values, a more continuous approach would yield

stronger arguments for the selected choices for these parameters. This could also be visualized as follows: Plotting Pearson correlation coeff., RMSE, Bias and maybe also the sample size in dependence on the parameters mentioned above (Hmin, Fmulti, Fcloud, Elidar). This might be more informative than the scatter plots from Figures 4-6. In order to quantify uncertainties (add a confidence interval) for these statistical measures (r, RMSE, Bias) a bootstrap analysis could be carried out (just an idea).

Furthermore, the overall r, RMSE and Bias should also be considered in dependence on the distance to the ceilometer (-> get a sense of the assumption of a homogeneous CBH field), some other cloud scene characteristics, such as number of valid VFM CBH retrievals within scene, CGT, CBH and/or CTH (get a sense if the error depends on the cloud scene). A distinction by day and night would also be beneficial. Depending on the nature of the bias, a bias corrected RMSE might be more appropriate.

Some quantification of the algorithm efficiency would be desirable which quantifies how often a successful retrieval is possible compared to the total number of cloudy scenes. How does the total number of CALIPSO overpasses split into cloud free scenes, valid retrieval, or neglected by criteria? Additionally, reasons for failure could be distinguished. Is there a distinct distribution globally, where the algorithm works effectively or not?

Specific comments

Line 15: Should be clarified whether the sentence refers to the author's study, or is meant generally.

Line 47: Could also cite Merk et al. 2016 (https://doi.org/10.5194/acp-16-933-2016) regarding adiabatic assumption

Line 79: Mülmenstädt et al. 2018 extrapolated CBH information from a surrounding field onto profiles for which the LIDAR signal was attenuated using CALIOP's VFM. It should be clearly stated that their study constitutes the basic idea for this study. Therefore, their retrieval approach should be explained in a bit more detail.

Section 2.1. More information on the satellite data, such as orbit characteristics, equatorial overpass time, should be provided.

Section 2.2. Information regarding limitations of the ceilometer should be provided (e.g. detection range, temporal & vertical resolution)

I suggest to explain in more detail how the reference CBH based on the ceilometer measurements is derived. This should be done in this section (2.2.). It is mentioned in Section 3.3. that the 10 percentile of CBceilo is taken as the "true" CBH. What is the rationale behind that?

line 114: It would be worth mentioning what type of clouds can be expected at these two validation sites. The paragraph should be split here (new topic: data matching).

Line 115: "a scene of 1° is selected" – Is it 1° along the perimeter of the Eath in along-track direction? Please, clarify what this refers to.

Section 3.1. line 150: If a comparison with a retrieval based on the adiabatic assumption is included, more details should be provided on how this is carried out. However, this adiabatic assumption is rather uncertain as stated in the introduction, so this is a weak argument here. The authors could test how the horizontal resolution of the VFM influences the uncertainty of the derived CBH retrieval.

Figure 2: (a) Label-color correspondence is unclear and should be improved. (b) Caption states that light blue represents 333m even though the colobar indicates gray color.

Section 3.2, line 165: "we follow a main hypothesis" – I think, the authors mean "assumption" instead of "hypothesis".

Line 166: "which is the lifting condensation level of coupled clouds" – Remove. Repetition from above; also this assumption is applied generally. There is no filtering for coupled only clouds.

Line 167: If this assumption is valid, then the CBH from thin clouds may serve as a proxy. However, there is no proof of such validity. Citing Mülmenstädt et al. (2018) here might suggest that there is proof even though there is not.

Section 3.3, line 172: Sentence should maybe be rephrased. I perceive that the authors take the 10^{th} percentile of the Hmin distribution for each 1° scene.

Figure 4, caption: A brief explanation for R, y, Matching data number, RMSE, STD should be provided.

Section 3.4.3, line 264: Rejection criterion (d) needs further elaboration. How do such cases compare with the ceilometer reference?

Section 4, line 276: Need to introduce "R" as correlation coefficient since it was not introduced before. Also state which kind is used, I am guessing Pearson correlation coeff.

Section 5, line 294: Or are the blanks also due to more cloud free scenes (e.g. Sahara, Australia)?

Line 298: "The clouds with large CTHs are mainly distributed in the ocean area at low […] mainly over 2,000 m, which are consistent with the result of Sun-Mack et al." – change the beginning to: "Clouds with high CTHs occur mainly over ocean at low […]"; Further questions: "2,000 m" refer to surface height or CTHs? And what is consistent with Sun-Mack et al.?

Line 304: "That will be helpful […]" – What exactly will be helpful is not clear.

Figure 9 caption: Add that these are 2-year mean values.

Section 5.3., line 345: "More boundary layer clouds occur over land during the day-time than at nighttime" – maybe change to "Over land at middle and low latitudes, more boundary layer clouds are detected at day-time than at nighttime"

Section 6, line 371: "because of the flow of warm continental air" – It is the subsidence of warm dry air at the subsiding branch of the Hadley Cell.

Line 375: The CBH retrieval approach based on MISR observations (Böhm et al. 2019) is indeed limited by a 560m threshold height (over flat terrain). Below this height, no cloud retrievals are possible. The authors indicate here that this height limitation is at 700m which should be clarified. The method by Böhm et al. has proven to work effectively for stratocumulus clouds of the southeast Pacific where the heights compare well to ground-based coastal observations (Munoz et al. 2016, https://doi.org/10.1175/JCLI-D-15-0757.1). However, for the southeast Atlantic the heights appear lower and the here proposed method is consistent with Andersen et al., 2019 (https://doi.org/10.5194/acp-19-4383-2019) (cf their Fig. 3c). Here, the MISR-based

technique cannot capture the heights sufficiently.

Line 380: MISR on the Terra platform has a 10a.m. equatorial overpass time whereas CALIPSO passes the equator in the afternoon. These diurnal differences should be kept in mind in particular in tropical regions, where heavy convection takes place in the afternoon. In general comparisons to other methods should always be seen in the light of obvious differences (e.g. overpass time, different years considered). Böhm et al. and Mülmenstädt et al. used 2007-2009 and 2007-2008, respectively, for the global assessment which is 5 to 10 years prior to 2014 and 2017 which are utilized here. Neither of these studies can claim to have an actual climatology as these periods are all far too short.

It may be more appropriate to compare the resulting global averages to Mülmenstädt et al. as the same equatorial crossing times are given, and the methods are generally both based on CALIOP observations.

Point v. Orographic clouds (line 391 ff): In particular for regions with complex orography, the assumption of homogeneous CBH across a larger region is most likely validated. Therefore, care should be taken when cloud heights are assessed for these regions. I suggest removing this conclusion here including Fig. 15 d.

Technical corrections

Line 32: "(3) CBH and CGT […] are 1200 and 1500 m, respectively" – ambiguous; does the 1200m refer to CBH for the Amazon and Congo, or for CBH and CGT for the Amazon?

Line 41: Sentence should be rephrased. Suggest to substitute "play a crucial role in the formation of size and cenentration" by "and control size and number concentration"

Line 49: "It was shown recently […]" The meaning of this sentence is not clear to me, consider rephrasing.

Line 58: "wide-range" – no hyphen: "wide range"

Line 61: “satellite observation data.” – maybe just “satellite observations.”

Line 61: “The Suomi National […] (Baker, 2011)” – revise this sentence, maybe split into 2 sentences.

Line 65: “[…] and showed […]” – split sentence: “[…]. They showed […]”

Line 68: “Li et al. […] CloudSat is 540 m” – rephrase; do you mean, they compared their retrieval to CloudSat CBH retrieval and found a standard deviation of 540m?

Line 75: “have a good potential for retrieval” – substitute with “have the potential for accurate retrieval”

Line 87: “[…] we proposed in this study […]” – substitute with “we derived”

Line 88: “retrieve the global CBH […]” – modify “retrieve the global distribution of CBH […]”

Line 89: “The low-level clouds […] aerosol-cloud interaction research.” – additional motivation; consider moving to a previous paragraph.

Line 93: “CALIPSO-retrieved CBHs were validated against in situ ceilometer measurements in Section 4.” – I think, generally present tense should be used (“were” -> “are”) and change “in Section 4.” to “(Section 4).”

Line 93: “Based on the validated-CBH, CTH and CGT were retrieved globally […]” – no hyphen; also not clear if the CTH and CGT is based on the CBH? How do you mean?

Line 95: “in Section 5.” – shorten to “(Section 5).”

Line 95: “Several features” – maybe change to “Specific spatial patterns”

Line 95: “based on this high-precision cloud geometry information.” – remove this phrase

Line 135: “The objective of CBH retrieval is to retrieve the forming level of the clouds” – change to “The objective of the CBH retrieval is to retrieve the forming level of clouds”

Line 141: “[…] of CALIPSO VFM scenes that identified low-level water clouds.” – change to “for CALIPSO VFM scenes which are identified as low-level water clouds.”

Line 178: Sentence should be revised. Maybe start with “Extremely low Hmin are more prone to misclassification because […]”

Line 182: “which the center point to the ceilometer observation station within a distance of 150 km” – is missing a verb.

Line 211: “collected in that given […]” – change to “collected in a given […]”

Line 243: “Elidar was used to […]” – consider revising the sentence, maybe: “Elidar is used to determine the lowest penetration efficiency that can still provide valid cloud base information in this study, […]”

Line 246: “[…] that both have […]” – change to “that have both, a 333 m […] and a detectable surface […]”

Line 292: “in 2014 were also applied in this study to ensure most the grids” – change to “for 2014 were also applied in this study to ensure that most of the grids”

Line 295: “The CBH distribution (Figure 9a) shows most CBHs above surface in the land area are higher than over ocean.” – change to “The distribution of CBH above ground level (Figure 9a) shows that over land, CBHs are higher than over ocean.”

Line 300: “smallest” – change to “lowest”; “areas” – change to “regions”

Line 301: “which are mainly ~1,000m” – move next to CTH if it refers to that

Line 302: “Thus, shallow clouds with small CGTs (<800 m) mainly distributed at the mid latitude oceanic area and offshore areas with a percentage of ~10 %.” – change to “Thus, shallow clouds with small CGTs (<800 m) occur mainly over mid latitude oceanic regions and eastern margins of subtropical oceans with a percentage of ~10 %.”; What do the 10% refer to, cloud cover overall or portion of shallow low clouds?

Line 336: “land than over the ocean […]” – change to “land than over ocean”

Line 407: missing a verb

Line 408: “was tested and validated based on two in situ ceilometer measurements in 2017” – change to “was tested and validated based on observations for the year 2017 from two ceilometer stations”