Title: Satellite retrieval of cloud base height and geometric thickness of low-level cloud based on CALIPSO

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MS No.: acp-2020-1252

Iteration: Minor Revision

Dear Prof. & Dr. Johannes Quaas,

Very appreciate for your and the reviewer's comments. We have revised our manuscript in light of all the comments. We hope our revisions have addressed the raised issues. The changes have been highlighted in color in the manuscript, and summarized as follows.

1. In Introduction, we have revised the relevant descriptions and added references in accordance with the reviewer's comments.
2. We have explained and revised the descriptions that caused the misunderstanding in Sections 2.3 and 3.1.
3. The fitting regression equations in Figures 4-8 have been revised in the manuscript.

Please refer to changes in line with the reviewer's comments for more details. Thank you for your time.

Sincerely,

Xin and Yannian

Editor Decision:

Publish subject to minor revisions (review by editor) (14 Jun 2021) by Johannes Quaas

Comments to the Author:

Dear authors,

Reviewer #2 has a rather limited number of minor suggestions that I ask you to address in a (probably last) iteration.

Best regards,

Johannes

Changes in Line with the Comments of Referee 2

At first, very appreciate for your insightful comments and suggestions. We have revised our paper in light of your comments. The changes have been highlighted in color in the manuscript, and are summarized below.

General comments

Lu et al. "Satellite retrieval of cloud base height and geometric thickness of low-level cloud based on CALIPSO"

The authors have solved most of my concerns. I would recommend its acceptance for publication after some minor revisions.

Minor comments:

1. Line 42-43, For "The combination of cloud base updraft and CCN determines cloud base droplet concentration (N_d)", I wonder if this is correct since I think the cloud base droplet concentration should also be dependent on the supersaturation, wind shear, and so on.

   RE: Thank you for your comment. The description here has been revised as following:

   Paragraph 1 in Introduction:

   The cloud base droplet concentration (N_d) is determined by the cloud base updraft, CCN, supersaturation, wind shear, and so on, which in turn determines the cloud's albedo for a given liquid water path (Twomey, 1974;Sato and Suzuki, 2019).

2. Line 50-52, A recent study has also indicated this point and tried to improve the simulations of cloud cover, base and top heights, which is worthy to cite here too, Ma et al. (2018, Doi: 10.1002/2017MS001234).

   RE: Thank you for your suggestion. This reference has been added to the citation at Paragraph 2 in Introduction as "CBH and CTH are fundamental cloud properties that are required to be parameterized correctly for improving model simulations of climate and climate change (Grosvenor et al., 2017;Zhao and Suzuki, 2019;Lenaerts et al., 2020;Ma et al., 2018)".

3. Line 59-60, This is true for active remote sensing of satellites. For passive remote sensing of satellites, the CTHs could also be relatively easily obtained, while likely with large uncertainties.

   RE: Thank you for your comment. The description here has been revised as following:

   Paragraph 3 in Introduction:

   Although there is often a large uncertainty in the cloud top heights obtained from passive satellite observations, it is relatively simple to retrieve. In contrast, the retrieval of CBH is much more challenging but necessary for retrieving CGT.

4. Line 143-144, While I do not understand the rationale for "The lowest 10 % quantile of the CB_{ceilo} is determined as true CBH", I think it might be reasonable considering that Ceilometer often overestimate the cloud base height as indicated by Wang et al. (2018, Doi: 10.1016/j.atmosres.2017.11.021). If the authors could explain the rationale to me, that would be great. I also suggest the authors could use the study mentioned here to support the method used.

   RE: We use the lowest 10 % quantile of the CB_{ceilo} rather than the mean or minimum of the CB_{ceilo} as true CBH, because the mean is highly susceptible to the influence of developing higher-level clouds and the minimum may be influenced by instrument noise. In addition, the 10% quantile used is also consistent with the quantile used in this study for the retrieval of cloud base heights based on CALIPSO satellite observations.

Accordingly, the description here also has been revised as you suggested:

Paragraph 1 in Section 2.3:

To avoid the underestimation of low CBHs and overestimation of high CBHs by ceilometer due to the influence of developing higher-level clouds and ceilometer measurement noise, the lowest 10 % quantile of the CB_{ceilo} is determined as true CBH (Wang et al., 2018).

5. Line 179-181, you may revise the sentence to state more clearly. Based on the descriptions before this sentence, I would say a resolution higher than 333 m could be better. I think what you would like to say is "compared to previous studies based on coarse spatial resolution satellite data".

RE: Sorry for that confusion. 333 m is the highest resolution of the CALIPSO satellite as shown in Figure 2b. We have added the relevant description as following:

Paragraph 1 in Section 2.1:

The VFM also provides the thermodynamic phase of cloud layers (water cloud, ice cloud) and horizontal resolution (333 m, 1 km, 5 km, 20 km, 80 km) that the retrieval was based on.

Accordingly, the description here has been revised as you suggested to make it more clearly:

Paragraph 2 in Section 3.1:

Therefore, it is more reliable to use the water cloud information with the highest resolution of 333 m to retrieve the CBH of low-level clouds compared to previous studies based on coarse spatial resolution CALIPSO satellite data.

6. Figure 4 d) The xtitle is necessary.

RE: Thank you for your suggestion. We have added the xtitle of Figure 4d as shown below.

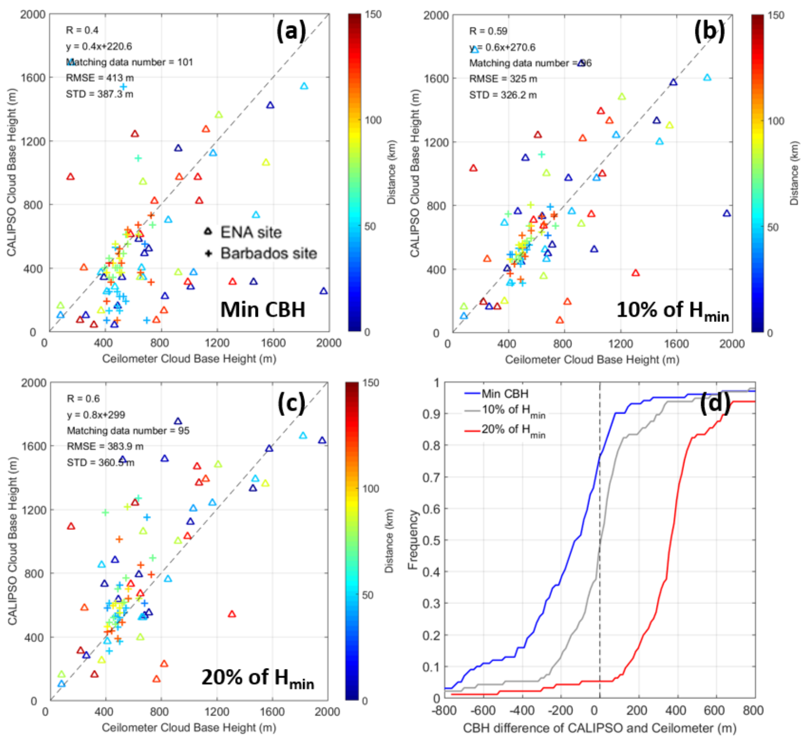

Figure 4: (a) Scatter plot of CALIPSO CBH (the minimum CBH for each 1° scene) and ceilometer CBH at two marine sites in 2017. The triangle represents the data for the ENA site, and the crosses represent the data for the Barbados site. The color represents the shortest distance from the CALIPSO ground track to the ceilometer site. R is the Pearson correlation coefficient, y indicates the linear fitting relationship between ceilometer CBH and CALIPSO CBH, matching data number is the data amount of the scatter plot, RMSE is the root-mean-square error and STD is the standard deviation. (b) and (c) are the same as (a), but for CALIPSO CBH at 10 % quantile of H_{min} and 20 % quantile of H_{min}, respectively. (d) Cumulative distribution of the difference between CALIPSO CBH and Ceilometer CBH at two sites in 2017.

7. Line 223, “:” -> “.”

   RE: This “:” has been revised as “.” at Paragraph 1 in Section 3.3.

8. Figure 8, What are the fitting regression equations shown in the figures? They are too weird to me with so large slope and intercept values.

   RE: Thank you for pointing it out. Yes, the fitting regression equation here was incorrect, we have corrected it in Figure 8 as showed below. Also other fitting regression equations have been updated (Figures 4, 5, 6, and 7) in the manuscript.

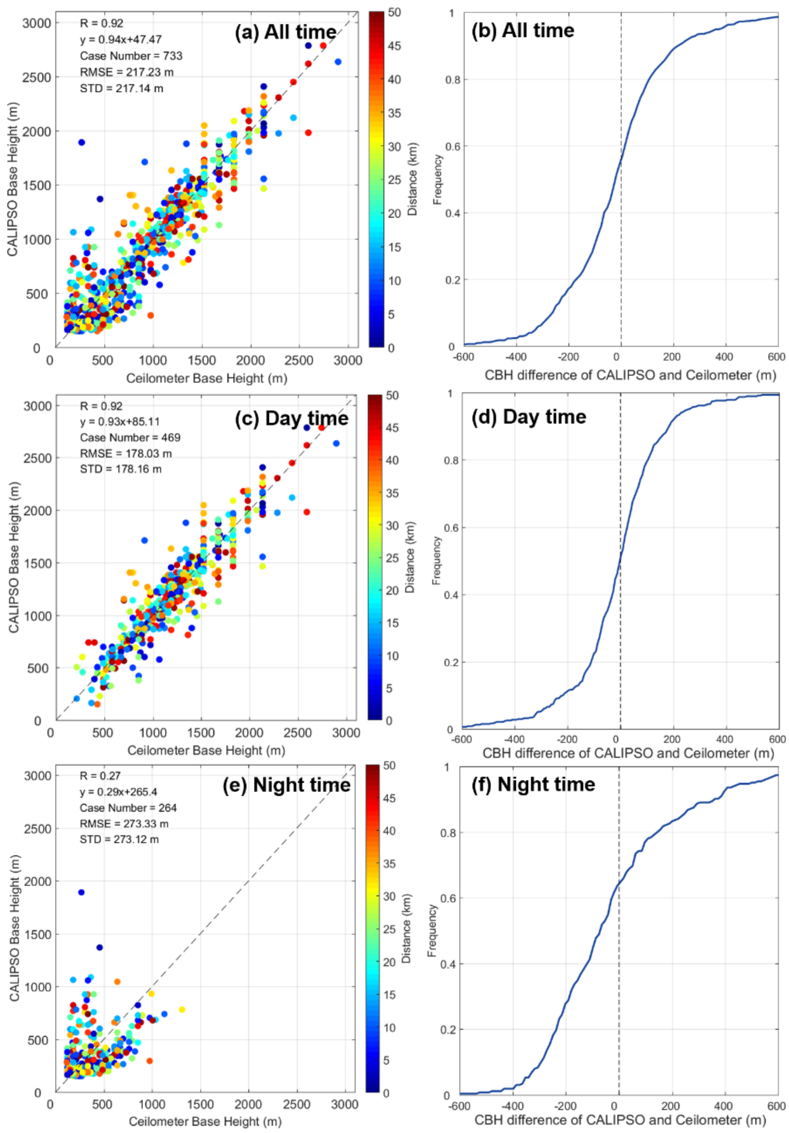

Figure 8. Validation of CALIPSO-retrieved CBH against 138 continental ceilometer sites in the southern Great Plains in 2017-2020. (a) Scatter plot of CALIPSO CBH and ceilometer CBH on all-time. The color represents the shortest distance from the CALIPSO ground track to the ceilometer site. (b) Cumulative distribution of the difference between CALIPSO CBH and Ceilometer CBH on all-time. (c)/(e) and (d)/(f) are the same as (a) and (b), but for day-time and night-time, respectively.

Reference

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