Author Response and Manuscript Revision

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September 2023

Dear Dr. Lebsock,

Please find our response to the second round of Reviewers comments and our revised manuscript.

We have tested the influence of cloud threshold value on cloud detection and found that 6 x 10^{-6} m^{-1} sr^{-1} is more suitable for Macquarie Island than previous default threshold value (2 x 10^{-6} m^{-1} sr^{-1}). This new threshold avoids false detection of boundary layer aerosol but remains satisfactory detection of clouds. We re-ran the ALCF with the new cloud threshold value and found a significant reduction of surface CFO. In addition, we have added additional discussion for the influence of precipitation and fog on observational low-level CFO. We hope that our further explanation and changes satisfy both you and the Reviewers.

Kind regards,

Mr. Zhangcheng Pei

Response to Reviewer 1:

Overall comments:

After reviewing your response, it seems clear that the approach taken for observational data (black lines in Figs. 8 & 9) is resulting in an overestimation of the near-surface cloud frequency of occurrence. You define a minimum threshold of ceilometer backscatter based on Kuma et al. [2021], but it seems you have not attempted to screen for precipitation occurrence (if I have misunderstood this, please clarify!).

Yes, the default minimum threshold value (2×10^{-6} m^{-1} sr^{-1}) we used to detect cloud overestimated near-surface CFO, which was influenced by precipitation, fog, and aerosol. We have picked several days when there are a lot of misidentified clouds to test different threshold values. We found that 6×10^{-6} m^{-1} sr^{-1} is suitable for Macquarie Island to remove the effect of boundary layer aerosol. The surface CFO was reduced from ~ 60% to ~35%. Our conclusions of CFO regarding radiation biases haven't changed. However, we have not screened for precipitation occurrence as we don't have disdrometer or rain gauge data for this specific period (Sep 2017 – Feb 2018).

Line-specific comments:

Line 263-264: "The cloud detection algorithm typically identifies observed precipitation as "cloud", whereas the simulated profile does not show any backscattering in the area where precipitation is occurring."

Does this mean that the precipitation which had erroneously resulted in a cloud detection is then corrected (no backscatter → no cloud)? It seems this is the case for the simulated but not the observed profiles, but again, please clarify.

The precipitation was not distinguished from clouds in observation as it can produce as strong backscatter as cloud. The model doesn't suffer this problem as it simulates backscatter based on cloud properties such as cloud fraction and liquid/ice mass mixing ratio, but not on precipitation properties. For this reason the simulated profile does not show backscattering for precipitation.

Line 264-267: "Upon reviewing the backscatter profiles, certain layers beneath stratocumulus clouds are identified as clouds, potentially consisting of drizzle, snow, fog, or aerosol. Nevertheless, the frequency of such occurrences is insufficient to significantly impact the statistics in a manner comparable to the

model bias. Stanford et al. (2023) found ceilometer on Macquarie Island was obscured 2.5 % of the time because of fog."

Even if fog occurs only 2.5% of the time, you are neglecting to emphasize the extent to which drizzle might be biasing the low-level CFO pictured in Figs. 8 & 9. In Tansey et al. [2022] we estimate small-particle precipitation (drizzle) occurrence to be ~36% at the MICRE site. How is this impacting the observation CFOs in your plots?

Yes, the small-particle precipitation should be emphasized to be able to increase the low-level CFO. Tansey et al. (2022) use the dataset from April 2016 – March 2017, which is different from our study period for CFO here (September 2017 – February 2018), but the results still can be referred to to show the frequency of precipitation occurrence at Macquarie Island.

Suggestions:

1) At the very least, discuss this uncertainty in the chosen approach: precipitation, which occurs very often at Macquarie Island, is causing backscatter near the surface to surpass your detection threshold and thus, the observational data's low-level CFO is overestimated (possibly by as much as >30%). It is not sufficient to state that the frequency of precipitation does not significantly impact the statistics, without providing some quantitative reasoning.

We have added the discussion as below.

Line 497: Nevertheless, it is crucial to note that limitations exist in ALCF for reproducing CFO. As mentioned in Section 2.6, ALCF doesn't identify precipitation, which could be classified as cloud in the ceilometer while ignored in the model (Kuma et al.,2021). This may cause an overestimation of CFO near the surface in the ceilometer and potentially amplify the underestimation of low-level CFO in the model. Upon visually inspecting the time series of ceilometer backscatter profiles, certain layers beneath stratocumulus clouds at around 500 m are identified as clouds, potentially consisting of drizzle, snow, or fog. Tansey et al. (2022) has reported an occurrence of 34% and 19% of drizzle in 2016-17 spring and summer at Macquarie Island. Moreover, Stanford et al. (2023) found that ceilometer observations on Macquarie Island were obscured 18 % of the time because of fog, which is also likely to influence the CFO near the surface. Hence, low-level CFO below 500 m should be interpreted cautiously as it could be influenced by the combination of precipitation and fog. Further research that combines lidar/ceilometer with precipitation measurements will be beneficial to the model evaluation. Moreover, more sophisticated algorithms to classify precipitation, fog, and aerosol are suggested to be developed within ALCF.

2) Kuma et al. discuss how precipitation may account for disagreement between simulated and observed profiles and they suggest screening for this: "If desired, the attenuated volume backscattering coefficient profiles affected by precipitation can be excluded before the comparison or their fraction determined by visually inspecting the observed attenuated volume backscattering to assess their possible effect on the statistical results." You might attempt to exclude precipitation, e.g. by defining cloudy bins only above the estimated CBH; neglect bins below CBH that are likely drizzle, and re-calculate the black lines in Figs. 8 & 9.

We have tried to exclude precipitation by neglect bins below CBH observed by Vaisala CL51 ceilometer. While we found that, in many situations, the Vaisala CBH is in the middle of the cloud instead of the bottom (Figure 1), which may be due to its algorithm or calibration method. Thus, this method is not so valid for removing the effect of precipitation.

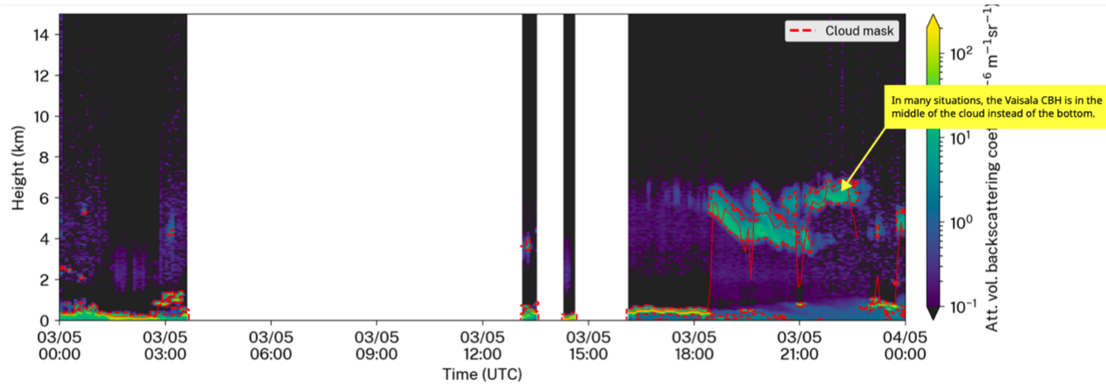

Figure 1: Attenuated volume backscattering coefficient profile with CBH from Vaisala CL51 ceilometer.

As we don't have disdrometer or rain gauge dataset from this period, we are not able to exclude precipitation and fog's effect in this work. We have raised caution about the low-level CFO, and that we should involve precipitation measurements for comprehensive model evaluation for in future studies. Moreover, ALCF is suggested to develop algorithm that can classify precipitation and fog.

Response to Reviewer 2:

In response to concerns raised by Reviewer 1 regarding high low-level COF in Figures 8 & 9, you state the following: "Stanford et al. (2023) found ceilometer on Macquarie Island was obscured 2.5 % of the time because of fog." While Stanford et al. did indeed find the ceilometer was obscured 2.5 % of the time, likely due to fog, they also did a more formal analysis of fog and found 18 % of all profiles to be representative of fog (i.e., high surface RH and completely attenuated layers very close to the surface). I think this should be mentioned since fog is likely influencing your COF at low levels. However, I also think this is okay since fog is still cloud, and you explicitly state your attenuated backscatter coefficient threshold and support it through citation of Kuma et al. (2021). Should you wish, you could show the sensitivity to this threshold (perhaps in an Appendix) showing a plot where the x-axis is the attenuated backscatter coefficient threshold, the y-axis is height, and contours would represent the COF for a given threshold. This is not necessary since you state and support your threshold, but could be an extra supportive measure.

We have added the discussion of influence of precipitation and fog on low-level COF.

Line 497: Nevertheless, it is crucial to note that limitations exist in ALCF for reproducing CFO. As mentioned in Section 2.6, ALCF doesn't identify precipitation, which could be classified as cloud in the ceilometer while ignored in the model (Kuma et al.,2021). This may cause an overestimation of CFO near the surface in the ceilometer and potentially amplify the underestimation of low-level CFO in the model. Upon visually inspecting the time series of ceilometer backscatter profiles, certain layers beneath stratocumulus clouds at around 500 m are identified as clouds, potentially consisting of drizzle, snow, or fog. Tansey et al. (2022) has reported an occurrence of 34% and 19% of drizzle in 2016-17 spring and summer at Macquarie Island. Moreover, Stanford et al. (2023) found that ceilometer observations on Macquarie Island were obscured 18 % of the time because of fog, which is also likely to influence the CFO near the surface. Hence, low-level CFO below 500 m should be interpreted cautiously as it could be influenced by the combination of precipitation and fog. Further research that combines lidar/ceilometer with precipitation measurements will be beneficial to the model evaluation. Moreover, more sophisticated algorithms to classify precipitation, fog, and aerosol are suggested to be developed within ALCF.

Additionally, we have picked up several days when there are a lot of misidentified cloud to test different threshold values. We found that 6×10^{-6} m^{-1} sr^{-1} is suitable for Macquarie Island to remove the effect of boundary layer aerosol. The surface CFO was reduced from ~ 60% to ~35%. Our conclusions of CFO regarding radiation biases haven't changed.