Dear editor,

We sincerely appreciate you and the anonymous reviewers for valuable comments and suggestions on our manuscript, again.

We have carefully considered these comments and suggestions, and have revised our manuscript accordingly.

The point-by-point responses to the reviewers are provided, along with the revised manuscript showing tracked changes.

With best regards,

Huang Kaiming

Response to Referee #1,

We sincerely appreciate your insightful comments and suggestions, which have greatly contributed to improving our manuscript.

According to your suggestions, we revised our manuscript, and presented a point-to-point reply to your comments.

Comments.

1. On my former first general comment where I pointed out that the focus and aim of the paper should be more clear, authors mention that it is addressed in the last paragraph of section 1; and it is more explained there, but still a further explanation is necessary.

Combining the suggestion in PDF, we rewrite the Abstract in the revised manuscript, as follows,

"Using the vertical velocity (w) observed by a Ka-band millimeter wave cloud radar (MMCR) at Wuhan, we investigate the evolution of convective boundary layer height (CBLH) based on a specified threshold of vertical velocity variance (σ_w^2). The CBLHs from the MMCR w in the selected durations are compared with those estimated by the lidar range corrected signal (RCS) and radiosonde temperature based on different algorithms, showing good agreement with each other. Although these algorithms are on basis of different dynamic and thermodynamic effects, the diurnal evolution of CBLH from MMCR is generally consistent with that from lidar, except for a few hours post-sunrise and pre-sunset due to the influence of aerosol residual layer on the lidar RCS. Meanwhile, the CBLH from MMCR shows less variation in occurrence of sand and dust, and swifter response of thick clouds, relative to that from lidar. In this case, σ_w^2 of the MMCR w identifies the CBLH based on dynamic effect, which can accurately capture the diurnal evolution of CBLH compared with that from the change of long time-mixing aerosol concentration. The monthly and seasonal features of CBLH at Wuhan is revealed via the MMCR measurement. Hence, considering that the MMCR is capable of continuous observation in various weather conditions, the MMCR w with high resolution can be applied to monitoring the evolution of CBLH in different atmospheric conditions, which is helpful for improving our comprehensive understanding of CBL and dynamic processes in CBL."

And in the last paragraph of Introduction, we add the explanation as,

"In present study, we estimate the CBLH based on the vertical velocity from a Ka-band millimeter wave cloud radar (MMCR) at Wuhan, and compared this result with that derived from the lidar RCS by three algorithms, and from radiosonde data by two algorithms. These algorithms are on basis of different dynamic and thermodynamic effects, respectively, thus the comparison enhances our comprehensive understanding of CBL and retrieval algorithms."

2. When they say "algorithms" in line 122. There are algorithms based on thermodynamic characteristics (i.e. profiles of temperature and/or humidity), on dynamic characteristics (wind, turbulence) and on backscatter. A review of these different methodologies can be found in Kotthaus et al. (2023) (https://doi.org/10.5194/amt-16-433-2023). The algorithm utilized by the authors is clearly a dynamical one but that should be clearly stated and the capabilities and limitations that this approach has needs to be considered. Moreover it is compared with the RCS which as far as I understand is a backscatter-based algorithm. All this should be clearly assessed while the authors compare their methodologies.

According to your suggestion, we have added the description of algorithm in the last paragraph of Introduction as,

"In present study, we estimate the CBLH based on the vertical velocity from a Ka-band millimeter wave cloud radar (MMCR) at Wuhan, and compared this result with that derived from the lidar RCS by three algorithms, and from radiosonde data by two algorithms. These algorithms are on basis of different dynamic and thermodynamic effects, respectively, thus the comparison enhances our comprehensive understanding of CBL and retrieval algorithms."

And in Section 3.2 in the revised manuscript, we have added the capabilities and limitations of methods, as follows:

"σ_w^2 indicates the turbulence level under the current condition, whereas, RCS tends to reflect the variation in the concentration of long time-mixing aerosol particles caused by dynamic effects (Kotthaus et al., 2023). Hence, the threshold method is a dynamical algorithm, which is more effective in capturing the dynamic changes within the CBL compared to the aerosol concentration algorithm based on the lidar RCS. In this way, the MMCR observes the high-temporal resolution data of w, making it available for analyzing diurnal evolution of CBL in different months and seasons. However, based on earlier studies, the selected threshold values are subject to change across the different regions (Burgos-Cuevas et al., 2023; Schween et al., 2014; Pearson et al., 2010; Tucker et al., 2009)."

The added literature of Kotthaus et al. (2023) is listed in References.

3. The introduction is less repetitive and better structured as was asked by me, however still some asseverations should be more precisely stated, such as the ones pointed out in lines 66 and 80 (please see the corrected attached pdf for this).

Sorry, we couldn't find the specific comments at lines 66 and 80 in the PDF.

According to your suggestion, we added a detailed explanation for the two sentences, as follows,

“Radiosonde can obtain high-precision meteorological parameters, such as temperature, humidity, horizontal wind and pressure, providing the possibility of estimating CBLH through various algorithms”,

And “Wind profile radar can measure the atmospheric wind speed and direction by analyzing the Doppler shift of the backscattered waves of multiple beams. The electromagnetic beams are reflected back due mainly to the atmospheric refractive index change caused by the non-uniform vertical structure of the atmosphere, such as vertical gradients in temperature, humidity, and turbulence, thus received echo and retrieved wind from radar contain the information related to the atmospheric vertical structure.”

4. I had some comments in the abstract before, and changes have been made, however, it is still not accurate enough. Please see the specific comments on the abstract added to the pdf revised version and make the corresponding changes.

According to your suggestion, the Abstract is rewritten in the revision, and please see the Comment 1.

5. However, as a general comment on the abstract I want to highlight the fact that it barely deals with novel aspects of the paper. It does state that there are higher CBL heights coincident when there is stronger radiation, but that is a very well-known fact, so the authors should re-structure the abstract and stress more on what is actually a scientific novelty: the evaluation of the vertical velocity from the MMCR to investigate the CBL height. They should look into capabilities and limitations of this approach. And if it is capable of assessing diurnal and seasonal variabilities then say that, but do not state the sentences as if the novelty was that higher CBLHs correspond to higher radiation, because that is not a novelty.

In the revised abstract, we have restructured it to highlight the use of vertical velocity derived from MMCR to estimate CBLH:

“The results are compared with those estimated by range corrected signal (RCS) from lidar and temperature from radiosonde based on different algorithms. Although these algorithms are on basis of different dynamic and thermodynamic effects, the diurnal evolution of CBLH from MMCR is general agreement with that from lidar, except for a few hours post-sunrise and pre-sunset due to the influence of aerosol residual layer on the lidar RCS. Meanwhile, the CBLH from MMCR σ_w^2 shows less variation in occurrence of sand and dust, and swifter response of thick high-level clouds, relative to that from lidar. In this case, σ_w^2 of MMCR w identifies the CBLH based on dynamic effect, which can accurately capture the diurnal evolution of CBLH compared with that estimated from the change of long time-mixing aerosol concentration in lidar observation. The monthly and seasonal features of CBLH at Wuhan is revealed via MMCR measurement. Hence, considering that the MMCR is capable of continuous observation in various weather conditions, the MMCR w with high resolution can be applied to monitoring the evolution of CBLH in different atmospheric conditions, which improves our comprehensive understanding of CBL and the dynamic processes in CBL."

6. In the methodology I had pointed out that the specifications of the radar were missing and still this is the case for some, as it is pointed out in the pdf, please check specific comments there.

The MMCR is designed by the Atmospheric Remote Sensing Observatory (ARSO) of Wuhan University (WHU). Transmitter, antenna, servo, data processor and cabin are purchases from different manufacturers, respectively. The integration of radar system is carried out by the combination of Nanjing Industrial Company and WHU ARSO. The radar uses a continuous wave (CW) system, call WHU-CW MMCR. This radar was established by the ARSO in 2019. Now, we can synthesize a larger power of 60-80 W for transmitter, improving further the detection capability of radar.

In the revised manuscript, the sentence is rewritten as,

"The WHU-CW MMCR established by the ARSO adopted a continuous wave (CW) system, and is a Ka-band frequency-modulated continuous wave (FMCW) Doppler radar. The MMCR is installed in WHU, as shown in Figure 1."

7. In order to evaluate how well their vertical variance threshold methodology acts to estimate CBLH the authors compare with radiosonde at 0800 LT. This is valuable, however discussion is missing. Please answer these questions:

(1). What does "generally consistent" (line 238) mean in terms of standard deviation? or some other objective quantification that you should utilize to quantitatively, statistically and significantly compare both methodologies.

In the revised manuscript, we add the comparison of CBLHs from MMCR and radiosonde, and present the added figures as Figures 5 and 6.

The added description and figures are following as,

"σ_w^2 of MMCR w determines the CBL top from the perspective of dynamic effect, and the CBLH can be estimated from the temperature data based on the thermodynamic effect. Here, we compare the CBLH derived from the MMCR w with that from the radiosonde data. Radiosonde is typically launched in Wuhan at 08:00 and 20:00. Given that the sun has set by 20:00, we present the comparison at 08:00. The radiosonde data are provided by University of Wyoming from the website at https://weather.uwyo.edu/upperair/bufrraob.shtml. The vertical resolution of radiosonde data in Wuhan was approximately 0.5-1.0 km before June 2021, and then was improved to a range of tens to hundreds of meters at higher altitudes. Therefore, we select the high-resolution data in the days without precipitation for our analysis.

We estimate the CBLH from the radiosonde data by using the methods of potential temperature (θ) gradient and bulk Richardson number (Ri) threshold. The potential temperature gradient (Grd_θ) is calculated at two adjacent heights in the radiosonde data, and the CBLH is determined by the maximum gradient in the profile of Grd_θ (Seidel et al., 2010). The bulk Richardson number is expressed (Zhang et al., 2014; Seibert et al., 2000), as follows,

$$Ri(z) = \frac{(g/\theta_{vs})(\theta_{vz} - \theta_{vs})z}{(u_z - u_s)^2 + (v_z - v_s)^2 + (bu_*^2)} \tag{1}$$

where g is the acceleration due to gravity; z is the height; θ_v is the virtual potential temperature; u_* is the surface friction velocity; u and v are the zonal and meridional wind components, respectively; and b is a constant, which is usually set to zero due to the fact that friction velocity is much weaker compared with the horizontal wind (Seidel et al., 2012). The subscripts of z and s denote the parameters at z height and surface level, respectively. In the profile of Ri, the CBLH is identified when Ri firstly crosses a threshold value upward from the ground, and the threshold is typically taken as 0.25 in early studies (Guo et al., 2021; Seibert et al., 2000), which is chosen in the analysis.

Figure 5 shows the comparisons of CBLHs derived from the MMCR and radiosonde measurements at 8:00 on 21 and 25, July 2021, respectively. On 21, for a threshold of σ_w^2=0.3 m^2 s^{-2}, the CBLH of 0.39 km from the MMCR w is in agreement with that of 0.40 km from the radiosonde Grd_θ, which are slightly larger than that of 0.34 km from the radiosonde Ri. In contrast to this, on 25, the CBLH is 0.57 km from the MMCR w, which is consistent with that of 0.59 km from the radiosonde Ri, but is slightly higher than that of 0.45 km from the radiosonde Grd_θ. Nevertheless, in the whole, the results from all the three methods roughly agree with each other.

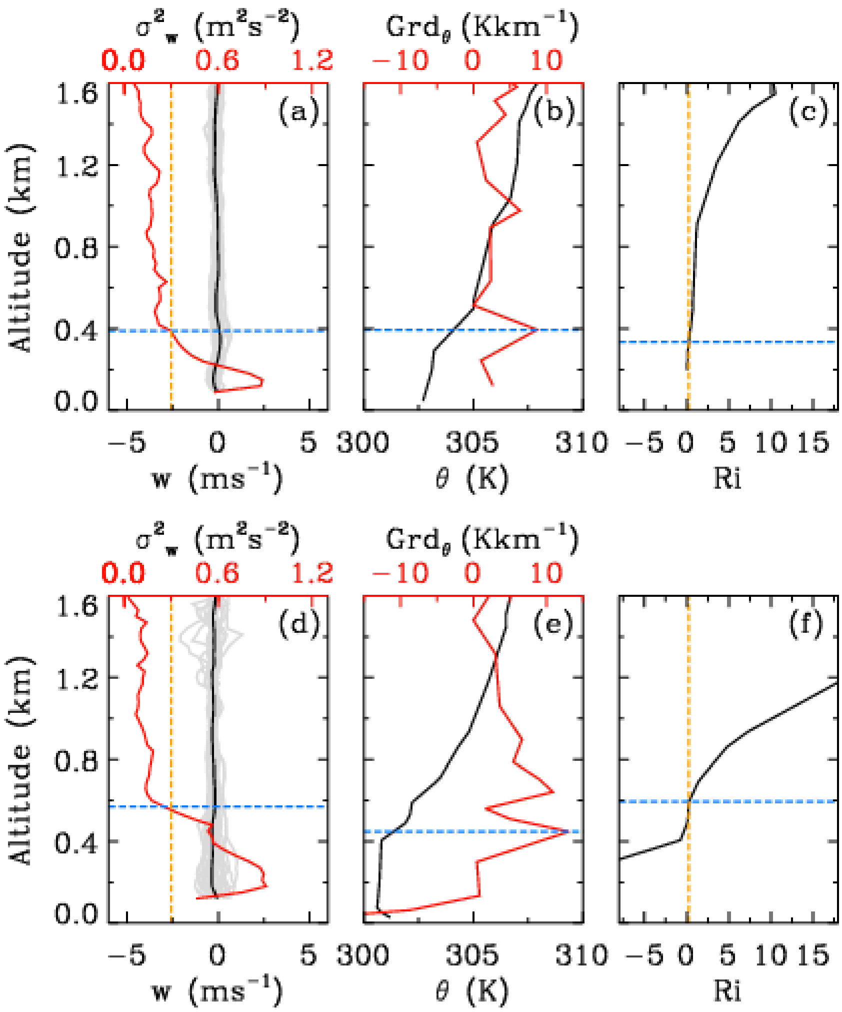

Figure 5. Comparison of CBLHs estimated by (a, d) threshold of σ_w^2=0.3 m^2 s^{-2} from MMCR, and (b, e) maximum gradient of θ and (c, f) threshold of Ri=0.25 from radiosonde data at 08:00 on (upper) 21 and (lower) 25 July 2021. In the panels 5a and 5d, the gray and black lines denote (lower horizontal axis) w and its mean value from MMCR, respectively, and the red and yellow lines denote (upper horizontal axis) σ_w^2 and the threshold of σ_w^2=0.3 m^2 s^{-2}, respectively. In the panels 5b and 5e, the

black and red lines denote (lower horizontal axis) θ and (upper horizontal axis) its gradient from radiosonde, respectively. In the panels 5c and 5f, the black and yellow lines denote Ri and the threshold of Ri =0.25 from radiosonde data, respectively. The blue horizontal line represents the position of identified CBL top.

Figure 6 displays the scatterplot of CBLHs identified by the MMCR w, and the radiosonde Grd_θ and Ri at 8:00 on the clear days in June and July 2021. The different variables and algorithms are used in the three methods, thus there are some differences of CBLHs derived from these methods, as shown in Figure 6. The CBLH from σ_w^2 of MMCR w has the correlation coefficients of 0.83 and 0.81 with that from the radiosonde Grd_θ and Ri, respectively, which are highly consistent with the correlation coefficient of 0.83 from the radiosonde Grd_θ and Ri. These results support the threshold of σ_w^2 = 0.3 m^2 s^{-2} applied to the CBLH estimation in Wuhan. In following analysis, we take 0.3 m^2 s^{-2} as the threshold to determine the CBLH in the MMCR observation.

It can be noted that the comparison focuses solely on the CBLH at 8:00 rather than the diurnal evolution of CBLH, owing to the lack of radiosonde observation. Consequently, we analyze the diurnal evolution of CBLH derived from the MMCR and lidar measurements."

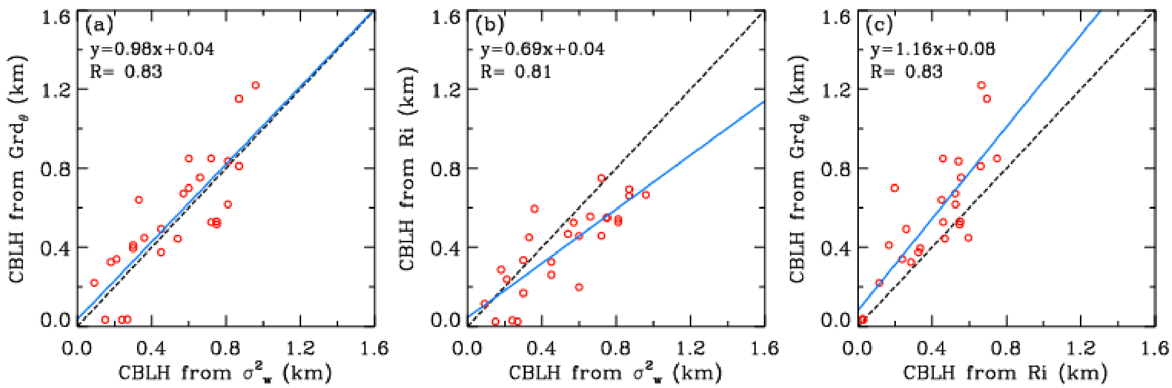

Figure 6. Scatterplot of CBLHs derived from (a) threshold of σ_w^2 =0.3 m^2 s^{-2} from MMCR vs. maximum gradient of θ from radiosonde, (b) threshold of σ_w^2 =0.3 m^2 s^{-2} from MMCR vs. threshold of Ri =0.25 from radiosonde, and (c) threshold of Ri =0.25 vs. maximum gradient of θ from radiosonde.

(2). How does the evolution of the diurnal cycle affects this comparison? At 8:00 am the convection in the

ABL should be starting to take place, so this corresponds to a growing boundary layer phase, therefore it is a good time to estimate it with the variance as you do it, that makes sense and the utilization of radiosondes is also valuable. But you need to discuss that this is a phase in which CBL is growing and it will grow more during the diurnal cycle, however I assume that there are no later radiosondes to compare with a more developed boundary layer, which is ok but also needs to be stated.

According to your suggestion, we have added the clarification in the revision as,

"It can be noted that the comparison focuses solely on the CBLH at 8:00 rather than the diurnal evolution of CBLH, owing to the lack of radiosonde observation. Consequently, we analyze the diurnal evolution of CBLH derived from the MMCR and lidar measurements."

(3). Authors utilize now also the threshold of the bulk Richardson number to estimate a boundary layer height. This is a valuable methodology but needs to be much further described. The equation of the Richardson number is added in the answers but not in the paper, please add it to the paper and explain how the calculations were made. Furthermore, the difference between gradient and bulk Richardson number should be clear, the equation written in the answers is correct but the explanation lack the fact that the potential temperature at each height and at the surface is considered (difference with the surface and not a continuous derivative as in the gradient).

According to your suggestion, we have added the explanation of calculation method, and please see the response in Comment 7(1).

8. I had previously a comment on what do authors mean by "subsidence" and now they changed it to "dip" answering to my comment. However, they still did not explain what do they refer when they now use "dip" please explain. In my perspective this is even more unclear now. Therefore, it is highly recommended to be changed in the paper. I think that the authors mean that the CBL height reduces, but I am really not sure and it is not clear in the paper what they refer to nor if there would be a physical mechanism explaining this.

Sorry for the unclear expression. You are right. We have replaced three "dip" with "obvious reduction", "evident reduction" and "reduction" in the revision, respectively.

9. On line 151 you say: "...a maximum unambiguous velocity of..." and it is not clear if you are referring to an uncertainty of the velocity or what is it, please be more precise and use scientific vocabulary.

According to your suggestion, "a maximum unambiguous velocity of 4.30 m s^{-1}" was replaced with "a maximum measurable velocity of 4.30 m s^{-1} without aliasing effect”.

Finally, we have made the correction about your suggestions presented in the supplementary PDF, and thank you for your careful and valuable suggestions on our manuscript, again.

Response to Referee #2,

We are grateful to your suggestion and recognition for our work. We have made correction in response to your valuable suggestion.

Comment.

1.The authors have adequately addressed all my concerns in my previous review. in this revision, the quality of this revision is much improved and I appreciate their efforts very much. Therefore, I am pleased to recommend its acceptance for publication at ACP. There is one in-text citation that is incorrect in line 81: Liu et al., 2020 can be revised to “Liu et al., 2019 (doi:10.1109/TGRS.2019.2918301)”.

According to your suggestion, “Liu et al., 2020” has been corrected as “Liu et al., 2019” in the revision. Thanks!