

Response to Referee 1

We are deeply grateful to you for your valuable comments and suggestions, which is of great help in improving our manuscript.

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

General comments

1. The focus need to be more precisely explained by the authors since the beginning. Mainly the methodology of RCS and the one of variance of vertical velocity are employed to derive CBLH and compared to each other. Furthermore, the authors investigate some study-cases (during August, November and March 2020) and then the monthly and seasonal variability of CBLH during the year 2020. However, it is not clear why the dates of the study-cases were chosen, that should be clearly stated. Moreover, it is not clear if they want to disentangle the variations of the two methodologies through the seasonal variability or they want to focus on particular dynamics of the study-cases. The focus and novelty of the present research should be much more clear and precise in order to be suitable for publication.

As you know, the lidar measurement is widely used to study the CBLH, however, this is not the case with the MMCR measurement. The four study-cases demonstrate that the MMCR measurement can obtain the CBLH diurnal evolution in different seasons, especially for the initial growth and final decay phases, meanwhile, the CBLH derived from the MMCR vertical velocity variance is less contamination by passing sand and dust and thick high-level clouds relative to that derived from the lidar RCS. On this basis, we investigate the monthly and seasonal features of CBLH over inland mid-latitude Wuhan based on the MMCR observation.

The four cases are not specifically selected, except to exclude precipitation, and severe sand and dust. Severe sand and dust cause the CBLH to be unidentifiable from the lidar RCS, whereas, this scenario is relatively common at Wuhan in spring. According to your suggestion, the chosen case is explained when each case is investigated.

According to your suggestion, we rewrite the last paragraph in Section 1, in which we

further explain the purpose and work in this study. Please see the revised manuscript.

2. There are many discussions that need to be further explained. The physical mechanisms that could be responsible for the difference between the two employed methodologies should be clear. Also, when attributing results to the “history of mixing” or to “seasonality “or “weather conditions”, there is often a lot of analysis and specifications lacking. This needs to be better addressed. Specific comments on that are mentioned later in the present review.

In the revision, we add some detailed explanation, for example, the more rapid response of aerosol vertical velocity to thick high-level clouds than its concentration. Please see more explanation in the Response to Comments later.

3. The introduction includes a lot of basic concepts of boundary layer that need to be better summarized. In its current state, the introduction is quite repetitive and includes too much basic information that is not necessarily relevant for the particular investigation nor referred to in the results.

According to your constructive suggestion, only PBL and CBL are presented in the revised manuscript, and the repetitive basic information is rewritten or deleted. Thus, the introduction has been simplified, and please see the revision and the Response to Comments later.

Specific comments:

1. Line 31: “The seasonal mean CBLH reaches the peak heights of 1.29 km in summer, 1.14 km in spring, and 0.6 km in autumn and winter, with occurrence time between 13:30 and 15:00 LT.” For being in the abstract, it would fit better to mention what do higher or lower CBLH mean or put it in terms of mean and standard deviation. What do the authors want to focus in here? Seasonal variability? Diurnal variability? That should be clear.

According to your suggestion, the sentence is changed as,

“The MMCR observation in 2020 depicts the diurnal evolution of seasonal and monthly mean CBLHs. The seasonal mean CBLH reaches the peak heights of 1.29 km in summer,

1.14 km in spring, 0.66 km in autumn, and 0.6 km in winter, indicating the dominant effect of radiation heating.”

2. Line 40: “ Atmosphere boundary layer is located in the lowermost layer of the troposphere, and directly impacts the air-land/sea interaction” It is not very precise, authors should better say something like: “The Atmospheric Boundary Layer (ABL) is located in the lower part of the troposphere, it is directly impacted by the surface forcings and thus it is in the ABL that the land-atmosphere (or land-sea) interaction takes place.”

According to your suggestion, we reword the sentence to be,

“The planetary boundary layer (PBL) is located in the lower part of the troposphere, and is where the air-land (or air-sea) interaction takes place, thus the PBL is directly impacted by the surface forcings.”

3. Lines 45 and 46: “Typically, the boundary layer top varies diurnally following the local surface temperature with a magnitude from a few tens of meters to several kilometers.” This sentence is not clear, what do authors mean by “following the local surface temperature”? I assume they refer to the surface forcing because of the solar radiation that heats the ground, but that should be explained, because there is no such a thing like “local surface temperature”. And then, it is also not clear what has a magnitude from a few tens of meters to several kilometers. I assume they are referring to the ABL height, but that should be explained, as well as the concept of ABL height.

Considering the different driving mechanisms and influencing factors of PBL, the sentence is corrected in the revision as,

“The height of PBL varies with local time, ranging generally from a few tens of meters to several kilometers at mid latitudes”.

4. From line 47 to line 54: The evolution of the ABL is explained, but that is very basic knowledge that needs to be better summarized and the focus of what part of this knowledge is useful for the present manuscript should be more clear.

According to your suggestion, the diurnal evolution of CBL is transferred to the second paragraph and is reduced to be,

“On a clear day, the CBLH rises after sunrise and reaches its maximum in the afternoon.”

5. From line 58 to line 66: The authors are again explaining the diurnal evolution of the ABL, so it becomes repetitive and very basic explanations are re-phrased. The whole introduction should be re-structured in order to concisely explain the evolution of the ABL and the different zones that develop within it, and then the observations and methods that are used to estimate CBLH and its variations (there are also very basic concepts about this from line 75 to 80 that need to be better summarized). And the focus on what part of this is relevant to the present manuscript should be clear. In general a much more accurate and concise introduction is required.

According to your helpful suggestion, we restructure the first and second paragraphs. The first paragraph briefly introduces the PBL, and the second paragraph describes the CBL that we investigate in the manuscript.

We concisely explain the evolution of CBL, and slightly add the influence of cloud and humidity on the CBL, which is relevant to our manuscript. Please see the revised manuscript.

The description of radiosonde in lines 75-80 is briefly rewritten as,

“Radiosonde can obtain many meteorological parameters with high precision, providing the possibility of retrieving the CBLH through different algorithms.”

6. From line 120 to line 132: Better write: “At the initial stage of CBL formation in the morning and the rapid decline stage of CBL in the afternoon, aerosol particles in the residual layer may cause the CBLH to be overestimated ~~by about~~ several hundred meters. This discrepancy **is due to** ~~often reflects~~ the ~~historical effect~~ of aerosol mixing rather than the current situation of convectively driven turbulence (Burgos-Cuevas et al., 2023; Schween et al., 2014; Pearson et al., 2010). ~~In the~~ **When utilizing Doppler lidar data** ~~Doppler lidar observation~~, a specified threshold of vertical velocity variance is used to define the height of CBL top. This method has

been validated as reliable by comparison with the measurements from other equipment, and the sensitivity of threshold has been discussed across different sites (de Arruda et al., 2018; Manninen et al., 2018; Schween et al., 2014; Barlow et al., 2011; Pearson et al., 2010). ~~In contrast to lidar with~~ A disadvantage of lidar is that it has a large blind range and limited penetrating cloud capability, because of that it is valuable to utilize microwave cloud radar that offers good low altitude coverage and superior performance in cloud penetration. In the cloud observation, there always exist a weak echo layer near the surface, from which the vertical velocity can be retrieved. However, there are few reports utilizing ~~on the use of~~ vertical velocity obtained from Doppler cloud radar for the CBL investigations.”

Combing the other Referee’s suggestion, the paragraph is rewritten in the revision, as follows,

“At the initial stage of CBL formation in the morning and the rapid decline stage of CBL in the late afternoon (Dewani et al., 2023; Manninen et al., 2018; Schween et al., 2014; Barlow et al., 2011), aerosol particles in the residual layer may cause the CBLH to be overestimated several hundred meters. This discrepancy is due to aerosols from a long time-mixing process rather than the current situation of convectively driven turbulence (Burgos-Cuevas et al., 2023; Schween et al., 2014; Pearson et al., 2010). When utilizing Doppler lidar data, a specified threshold of vertical velocity variance is used to define the height of CBL top. This method has been validated by comparison with the radiosonde observation (Dang et al., 2019; Li et al. 2017; Granados-Muñoz et al., 2012), and the sensitivity of threshold has been discussed across different sites (de Arruda et al., 2018; Manninen et al., 2018; Schween et al., 2014; Barlow et al., 2011; Pearson et al., 2010). A disadvantage of lidar is that it has a large blind range and incapability to penetrate clouds, thus because of that, it is valuable to utilize microwave cloud radar that offers good low altitude coverage and superior performance in cloud penetration. In the cloud observation, a weak echo layer always exists near the surface, from which the vertical velocity can be retrieved. However, there are few reports utilizing vertical velocity obtained from Doppler cloud radar for the CBL investigations.”

7. Line 126: Which other equipment are the authors referring to? Radiosondes?

Yes, as you said.

“with the measurements from other equipment” is changed as “with the radiosonde observation (Dang et al., 2019; Li et al. 2017; Granados-Muñoz et al., 2012)”.

8. Line 142: “In this study, the CBLH derived from the MMCR ~~measurements~~ ~~observation~~ is compared...”

“observation” is changed as “measurements”.

9. Lines 146 to 151: “The ~~climate of the~~ city is ~~humid~~, dominated by the subtropical monsoon ~~humid-climate~~, which is characterized ~~with~~ by abundant precipitation and four distinct seasons (Guo et al., 2023). Due to heavy traffic and industrial activities, large amounts of aerosols are emitted from the industrialized metropolis. ~~Meanwhile~~, sandstorms from the northwest often pass through Wuhan, especially in spring. These sandstorms cause the remarkable variation in the spatial distribution and concentration of aerosols.”

These errors have been corrected in the revision.

10. Line 155: Important technical information about the MMCR is missing. What brand is it? What retrieval does it utilize? Is the mode utilized the only possible? What other modes are there and why is this one chosen?

Conventional microwave radar is pulse radar. After the antenna emits a pulse signal, echoes are received by the same antenna. The frequency-modulated continuous wave radar in the manuscript is a kind of new system radar. The transmitting antenna continuously emits microwaves, thus echoes need to be received by another antenna. The distance information of echoes is retrieved by demodulating the modulated continuous wave. Due to the continuous transmitting and receiving, the continuous wave radar has much larger mean power relative to pulse radar, which is why the MMCR in the manuscript can always receive weak echoes from aerosols near the ground.

According to your suggestion, we add the brand as “WHU-CW MMCR”.

We add and rephrase some descriptions, as follows,

“The radar system transmits a mean power of 50 W at operating frequency of 35.035 GHz through 0.38° width beam formed by a Cassegrain antenna with 1.5 m diameter. Backscatter echoes from aerosol and cloud particles are received by the other same Cassegrain antenna”;

“Because of almost continuous transmitting and receiving, FMCW radar has generally a much higher mean power relative to pulse radar, which improves the capacity of MMCR to detect weak echo targets. Meanwhile, by modulating and demodulating the continuous wave, the FMCW radar measurement has an adjustable range and time resolution.”

11. Line 171: What do authors refer to by “plankton”?

“plankton” is present as “aerial plankton” in early literature, which suggested the weak echoes near the surface from “small insects and aerial plankton”. Thus, “plankton and insects” is changed as “small insects and aerial plankton” in the revised manuscript.

12. Line 174: Remove “and so on” This kind of expressions are not accurate and therefore not suitable for a scientific paper.

“And so on” has been deleted.

13. Lines 179-200: All section “2.2 Polarization Lidar” needs to be re-structured, information about the location of the lidar and its technical characteristics are merged together. Then authors also talk about how the data is transmitted and retrieved. However, ideas should be more clearly addressed in a more ordered way. Perhaps first talk about location of the lidar, then about the most important lidar measurements characteristics (resolution, brand, configuration...) And finally about how the lidar measures and how it retrieves relevant information. The final paragraph (lines 198-200) is completely out of context, but that information should be mentioned in a more ordered manner.

According to your suggestion, we restructure the section, as follows,

“The WHU-PL polarization lidar developed by ARSO is also located in Wuhan University, about 0.5 km from the Ka-band MMCR. The lidar telescope is 70 m above sea level, which is about 30 m higher than the MMCR antenna. Expanded laser beam overlaps with the full view field of the receiving telescope at a height of 0.3 km, thus this height is the low limit of lidar detection. The lidar data has a temporal resolution of 1 min, and the same vertical resolution of 30 m as the MMCR data. In this study, we regard the height of MMCR antenna as a baseline, and then the initial height of lidar data is set at 0.33 km.

The lidar system consists of transmitting subsystem receiving subsystem and information processing subsystem. The lidar vertically emits the laser pulses of 120 mJ at operating wavelength of 532 nm with a repetition rate of 20 Hz by a frequency-doubled Nd: YAG laser. The output polarized laser beam has a fine polarization purity with depolarization ratio less than 1:10000 by using a Brewster polarizer. Light backscattered by aerosol and cloud particles and atmospheric molecules is collected by a telescope with 0.3 m diameter. After separated through an interference filter with 0.3 nm bandwidth centered at 532 nm, the elastically backscattered light is incident on a polarization beam splitter prism, and then the two-channel polarized light are focused onto two photomultiplier tubes (PMTs), respectively. The signals from the two PMTs are transferred to a personal computer (PC)-controlled two-channel transient digitizer, which can obtain the echo signal intensity and volume depolarization ratio through the PC processing. Backscatter coefficient is retrieved based on the backward iteration algorithm under the condition of a given lidar ratio proposed by Fernald and Klett (Fernald, 1984; Klett, 1981), and then the RCS is derived from the backscatter coefficient (Freudenthaler et al., 2009; Immler and Schrems, 2003). The lidar configuration and depolarization comparison with the measurement from the cloud-aerosol lidar and infrared pathfinder satellite observation (CALIPSO) were in detail described in the early study (Kong and Yi, 2015).”

14. Lines 203 and 204: ~~“In view of the CBLH derived from the vertical velocity (VV) in the~~

~~MMCR observation but from the RCS in the lidar measurement, we use different algorithms to determine the CBLH, respectively.”~~ Not clear, it needs to be completely rewritten in something like: “Given that the CBLH is estimated from instruments that retrieve different variables, the algorithms that are utilized to make such estimations are also based on different principles that are explained in the following subsections”.

In the revised manuscript, the sentence was modified as “Given that the CBLH is estimated from instruments that retrieve different variables, the algorithms that are utilized to make such estimations are also based on different principles, which are explained in the following subsections.”

15. Line 209: A sentence should be added before start talking about “The wavelet covariance...” This added sentence should briefly explain the physical mechanism because of which aerosol concentration is utilized as a proxy of ABL height. (Because it is assumed that the aerosols are able to mix below the ABL height).

According to your suggestion, the description before “The wavelet covariance...” is rephrases as,

“In the lidar observation, the CBLH is derived from the RCS, which is approximately proportional to the aerosol concentration (Kong and Yi, 2015; Lewis et al., 2013; Pal et al., 2010; Emeis et al., 2008). Generally, aerosols are well-mixed within the CBL due to the convectively driven turbulence, and its concentration decays sharply over the CBL top. Hence, the gradient (Grd) method is often utilized to investigate the CBLH by identifying the strongest or minimum gradient of RCS.”

16. Line 215: Authors need to specify variance of which variable are they referring to.

According to the Comments 16-19, we rewrite the paragraph, as follows,

“On the other hand, because of the entrainment process, there is a frequent exchange of matter and energy between the CBL and the free atmosphere, causing the dramatic variation of aerosol concentration or lidar RCS on small time scales around the CBL top (Zhang et al., 2018; Kong and Yi, 2015). In this case, the variance (Var) method is used

to determine the CBL top by identifying the maximum variance of RCS during a relatively long period (Lammert and Bösenberg, 2006; Martucci et al., 2004; Piironen and Eloranta, 1995). We estimate the CBLH from the lidar RCS in a period of 30 min by using the three methods, for instance, the CBLH at 12:00 LT (the same below) is calculated based on the RCS data from 11:45 to 12:15.”

17. Line 216: what do authors mean by “temporal domain”, they should explain this more precisely.

The unclear description is removed in the revision, and please see the Response to the Comment 16.

18. Lines 216-218: “The frequent exchange of matter and energy between the boundary layer and the free atmosphere causes the dramatical variation of aerosol concentration on small time scales around the CBL top.” This sentence needs a reference.

The reference is added. and please see the Response to the Comment 16.

19. Lines 220 and 221: “We estimate the CBLH from the lidar RCS every 30 min by using the three methods, and then the obtained height is marked at the central time of 30 min.” What do authors mean by “marked at central time”? Please explain and re-write.

The sentence is rephrased, and please see the Response to the Comment 16.

20. Line 223: Authors use VV for vertical velocity, it is more usual to utilize letter w for this and the greek letter sigma for the variance.

According to your suggestion, “VV” for vertical velocity is replaced by w , and “VV variance” is replaced by σ_w^2 .

21. Line 230: Please add how many measurements does that lapse include.

This sentence has been changed as “the threshold method is also used to determine a CBLH from the more than 6000 w profiles in the MMCR measurement during a

period of 30 min.”

22. Line 232: Why is 15th of August 2020 chosen? Any particular interest on this day study case? Are there any statistics to address how the three algorithms compare with each other?

Relative to the MMCR, the lidar has much less working days, especially for all-day operation. 15 August 2020 is chosen because 1) both the radar and lidar have the data; 2) it rained on 12 August 2020, which should have little influence on the analysis of CBLH on 15 due to two days of evaporation; and thus 3) the sunny 15 August with clouds only in the late afternoon have a good evolution of CBL.

By using the available lidar data, we compare CBLHs from the lidar RCS by the three methods and calculate their correlations. Figure S1 (only presented in the Response) shows the comparison of CBLHs between 7:00 and 17:00 from the perspective of local time and season, respectively. The chosen 7:00 and 17:00 are based on the sunrise and sunset in winter. Figure S2 shows the comparison of CBLHs from 2 h after sunrise to 2 h before sunset.

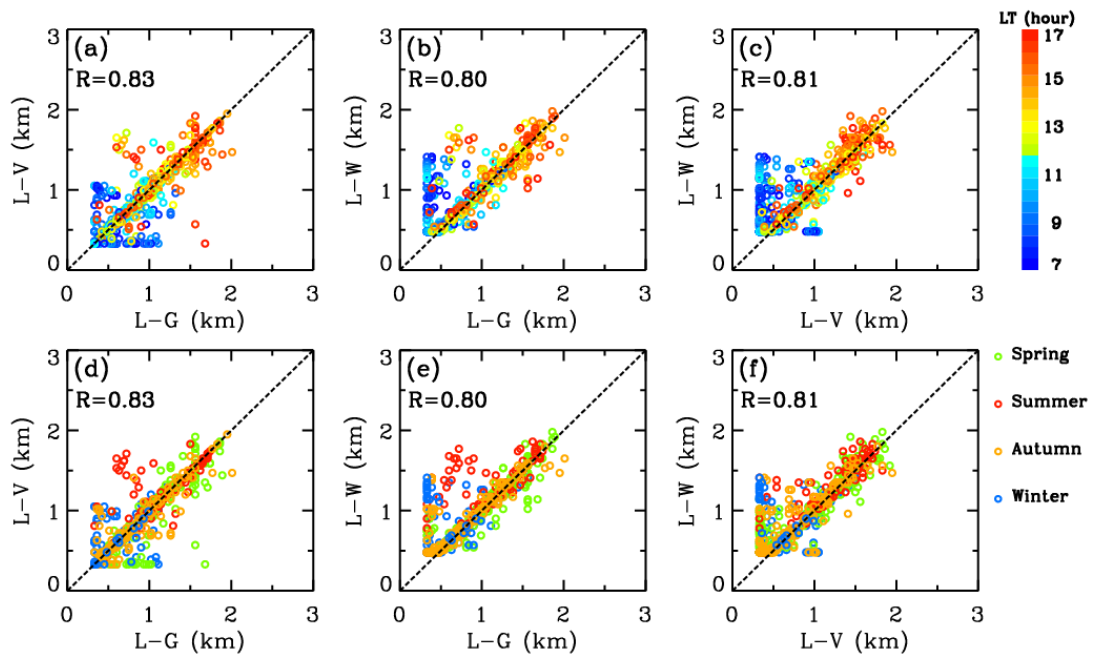


Figure S1. Comparison of lidar RCS CBLHs between 7:00 and 17:00 from the perspective of (upper row) local time and (lower row) season. L-G, L-W and L-V represent the Grd, WCT and Var methods, respectively.

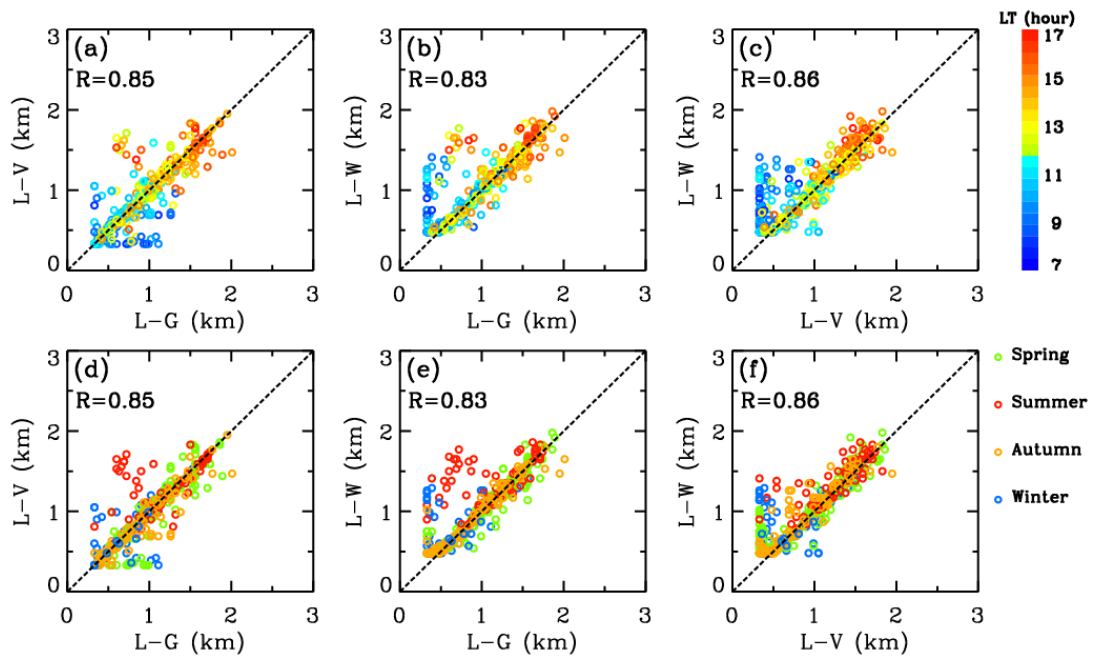


Figure S2. Comparison of lidar RCS CBLHs from 2 h after sunrise to 2 h before sunset according to the perspective of (upper row) local time and (lower row) season.

As shown in Figures S1 and S2, all the correlation coefficients are larger than 0.8, whereas, there are some differences between them, especially in the initial ascent phase. Their differences may be understandable because the three methods have the different physical principles or mathematical techniques.

In the revision, we add the description of “The day is 3 days later than the rainy day of 12 August.”

23. Line 243: “demonstrates that the MMCR VV variance is a fine proxy in the estimation of CBLH” How is this demonstrated if authors are simply comparing particular heights from the three methodologies in a particular study-case? Which one is more reliable? What processes are responsible for the matching or differences of these values? What are the synoptic conditions in the study-case? Is there any sensitivity study regarding that? Is there any idea of how seasonality affects the CBLH retrievals and how to relate this with your study-case?

Similar to the comparison of lidar CBLHs in the Response to the Comment 22, we further compare the MMCR CBLH with the lidar CBLHs by using the MMCR data in the same days as the lidar data. The comparison is presented in Figures S3 and S4 in the

form of scatter diagram.

Firstly, all the correlation coefficients between the MMCR CBLH and the lidar CBLHs is more than 0.66, however, these correlation coefficients are generally smaller than those between the lidar CBLHs.

Secondly, the differences between the MMCR and lidar CBLHs occur primarily in the initial ascent phase and the final descent phase, which is consistent with the results in the manuscript. The lower correlation in Figures S3 and S4 than in Figures S1 and S2 can be caused at least by 1) the large blind range of lidar; 2) the influence of aerosol residual layer on the lidar RCS; and 3) the response of aerosol concentration to weather condition variation is slower than the vertical velocity, as shown in the manuscript.

Thirdly, from the perspective of the season, 1) the lidar CBLHs in winter are generally higher than the MMCR CBLH, similar to the case in winter from the manuscript. We agree with your Comments 32 and 37. Since the CBLHs identified from the MMCR and lidar have different physical principles, the weak solar radiation and wet ground in winter may be responsible for the difference of CBLHs in winter. 2) the scatter diagram shows that there are more discrete points in spring relative to the other seasons. There are the frequent sand and dust activities at Wuhan in spring, which make a major contribution to this discrepancy between the MMCR and lidar CBLHs in spring. Additionally, the four cases in the different seasons from the manuscript show the discrepancies between the MMCR and lidar CBLHs, which are generally consistent with the statistical seasonal discrepancies, respectively. Thus, there aren't many causes of careful selecting for the four cases in the manuscript except for excluding the days with rainfall or very severe dust storms.

Finally, in Figures S4 and S4, the correlation coefficient of the MMCR CBLH with the lidar CBLH from Var method is larger than that with the lidar CBLH from Grd and WCT methods, similar to the result in the manuscript. The RCS gradient is the vertically variational rate of 30 min-mean RCS. However, although w and RCS are different physical variables, both their variances represent the deviation degree of their small time scale values relative to their 30 min-mean values, which may be the cause of the higher

correlation between the CBLHs from the two Var methods.

As shown in Figures S1-S4, when the CBL is well developed, the CBLHs derived from different methods have a higher consistency. As you implied, a particular case in the noon is not enough to draw a conclusion, hence, we delete “Hence, the good consistency of CBLH derived from the MMCR and lidar demonstrates that the MMCR VV variance is a fine proxy in the estimation of CBLH.” in the revised manuscript.

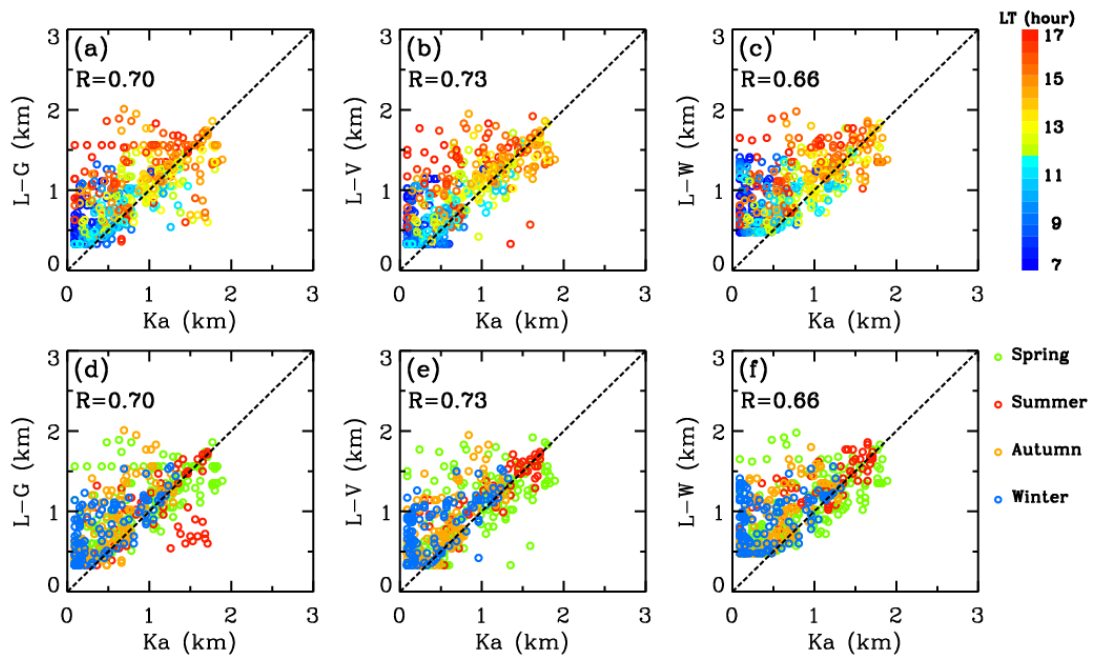


Figure S3. Comparison of MMCR CBLH with lidar RCS CBLHs between 7:00 and 17:00 from the perspective of (upper row) local time and (lower row) season. Ka represents the Var method from Ka-band MMCR, and L-G, L-W and L-V represent the Grd, WCT and Var methods from lidar, respectively.

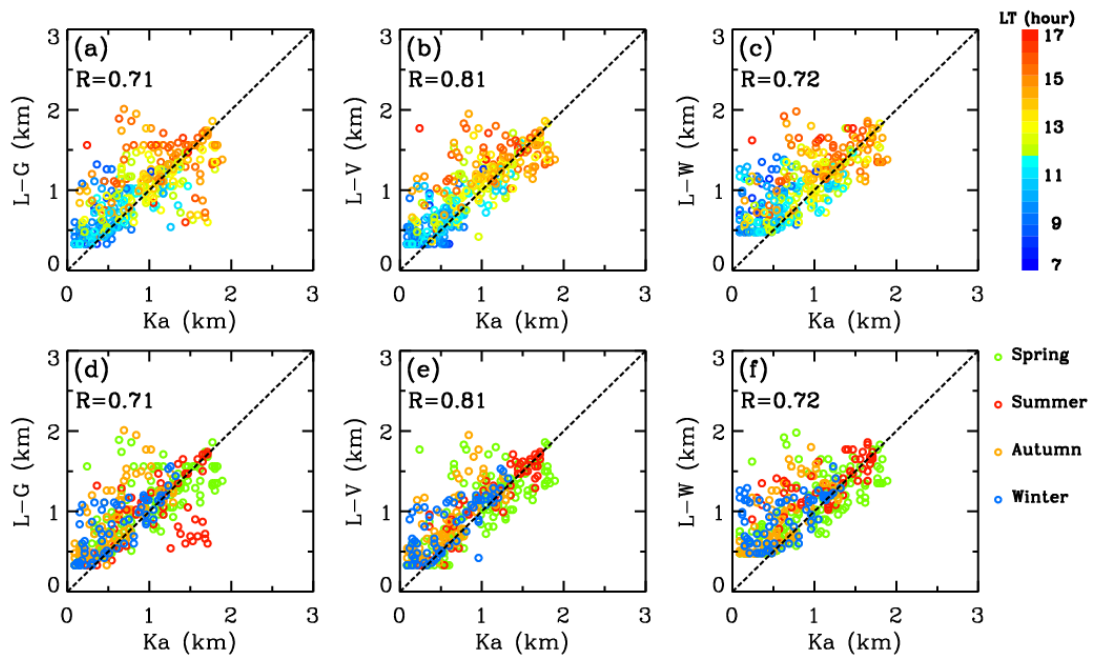


Figure S4. Comparison of MMCR CBLH with lidar RCS CBLHs from 2 h after sunrise to 2 h before sunset according to the perspective of (upper row) local time and (lower row) season.

24. Lines 246 to 252: Authors discuss here figure 4 in which CBLH is estimated for the same day with different thresholds, so a comparison and analysis of how this height varies is presented. However this is poorly discussed because the threshold is seen to highly impact the estimated CBLH in the morning growing phase and in the afternoon decaying phase of the boundary layer. Authors only mention particular time in the day but a more comprehensive explanation of these phases and the boundary layer evolution and dependence on the thresholds is lacking. As said in lines 247 and 248 the CBLH does not abruptly changes with the thresholds from 9:30 to 17:30, however this corresponds to the developed phase where a fully convective boundary layer is expected. Further analysis on the growing and decaying phases is required, as well as a comparison with other boundary layer height estimation with other thresholds that could also help to argue why the threshold of $0.3 \text{ m}^2\text{s}^{-2}$ is chosen. Also, it would be helpful to include sunrise and sunset times.

According to your constructive suggestion, we compare the MMCR CBLH with the radiosonde CBLH. The radiosonde data are provided by University of Wyoming at the website of <https://weather.uwyo.edu/upperair/bufrraob.shtml>. The Radiosonde data at

Wuhan have a very rough vertical resolution of about 0.5-1.0 km before June 2021, and since then, the vertical resolution has been improved to tens to hundreds of meters in the thousands of meters above the surface. The sun has gone down at 20:00, thus we present the comparison at 8:00 in some days without precipitation.

We identify the CBLH by the maximum gradient of potential temperature (θ) and a 0.25 threshold of bulk Richardson number (Ri) based on the radiosonde data (Guo et al., 2021; Seidel et al., 2010; Seibert et al., 2000). The bulk Richardson number is expressed (Guo et al., 2021; Seidel et al., 2010; Seibert et al., 2000) as follows:

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

where g is the gravitational acceleration; z is the height; θ_v is the virtual potential temperature; u_* is the surface friction velocity; u and v is 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.

Figure S5 presents the comparison of CBLHs derived from the three methods at 8:00 in some days. Firstly, as shown in Figure S5, the CBLH from the threshold of $\sigma_w^2=0.3 \text{ m}^2 \text{ s}^{-2}$ from MMCR is generally consistent with the CBLHs from the gradient of θ and the threshold of $Ri=0.25$ from radiosonde, which indicates that the threshold of $\sigma_w^2=0.3 \text{ m}^2 \text{ s}^{-2}$ should be appropriate for the CBLH estimation at Wuhan. Nevertheless, there is also a little difference in the results from the three methods because these methods have the different physical principles.

Secondly, the CBLH at 8:00 shows a change from day to day in the same month, and even in three straight sunny days of 20-22 July. A possible cause is that the other factors may have a relatively important impact on the CBLH in the initial growing phase relative to the turbulence driven primarily by surface heating in the noon.

Thirdly, when there is a rapid reduction around $\sigma_w^2=0.3 \text{ m}^2 \text{ s}^{-2}$ with height increasing,

the estimated CHLH is insensitive to the thresholds. Whereas, in the initial growing phase, the slow reduction around $\sigma_w^2=0.3 \text{ m}^2 \text{ s}^{-2}$ may occur, too, leading to that the threshold is seen to highly impact the estimated CBLH. We conjecture that the relatively important impact of the other factors on σ_w^2 besides surface heating may be responsible for the σ_w^2 variation in the initial and final phases.

Sorry, this MMCR did not work routinely for many days or several months in 2021 due to the epidemic and the transmitter returned to the factory for maintenance, thus the MMCR data in only 2020 is used in the investigation.

According to your suggestion, we add the sunrise and sunset times in Figure 4, and the sentence as follows,

“By comparison (not presented), the CBLH at 8:00 derived from the threshold of $\sigma_w^2=0.3 \text{ m}^2 \text{ s}^{-2}$ is generally consistent with the CBLHs estimated by the maximum gradient of potential temperature and a 0.25 threshold of bulk Richardson number based on the radiosonde data at Wuhan, which indicates that the threshold of $\sigma_w^2=0.3 \text{ m}^2 \text{ s}^{-2}$ is appropriate for the CBLH estimation at Wuhan”.

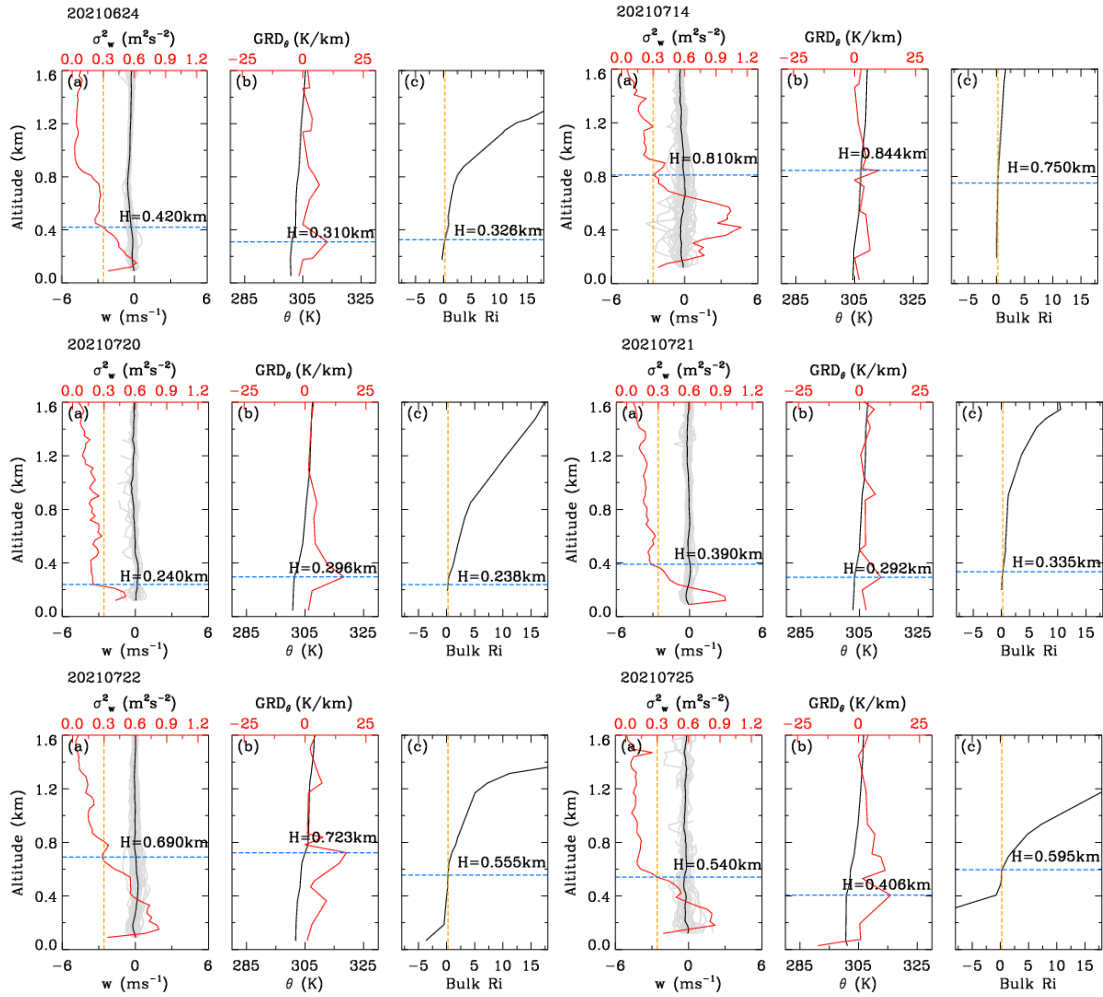


Figure S5. Comparison of CBLHs estimated by the $\sigma_w^2=0.3 \text{ m}^2 \text{ s}^{-2}$ threshold from MMCR, and the maximum gradient of θ and $Ri=0.25$ threshold from radiosonde data at 8:00. There are the three panels in each day, and the blue horizontal line denotes the position of estimated CBL top. In the panel (a), the gray thin and black thick lines denote w and their mean values from MMCR, respectively; the red line denote σ_w^2 ; and the yellow line denotes the threshold of $\sigma_w^2=0.3 \text{ m}^2 \text{ s}^{-2}$. In the panel (b), the black and red lines denote θ and its gradient from radiosonde, respectively. In the panel (c), the black line denotes Ri from radiosonde data, and the yellow line denotes the threshold of $Ri=0.25$.

25. Lines 259-261: “It is interesting that the CBLH from the lidar RCS variance drops at 07:30, and then shows a change similar to that from the MMCR VV variance.” Authors should mention what physical mechanism could be responsible for that behavior that is coincident with the two techniques.

As shown in Figures S3 and S4, the statistical results also indicate that the correlation coefficient of the MMCR CBLH with the lidar CBLH from Var method is larger than that with the lidar CBLH from Grd and WCT methods.

In the revised manuscript, we add the explanation as,

“Both the variances of w and RCS represent the deviation degree of their small time scale values relative to their 30 min-mean values, which may be responsible for the similar results.”

26. Lines 264-267: One can note from the reflectivity factor distribution in Figure 5b that cirrus clouds occur from 17:00, develop rapidly into the thick clouds at about 11-14.4 km at 17:30, and then dissipate quickly after 17:30. In the MMCR observation, the cirrus appearance makes a large contribution to a clear dip in the CBLH between 17:30 and 18:30,...” It is not clear what is the interest or the particular feature that the authors want to study with this. Please explain how this findings relate to the focus and in the context of your research.

Combining the next Comment 27, we understand what you mean, clouds have a complex influence of on turbulence in the CBL, which may cause an insufficiently focused purpose in the study.

The CBLH in our manuscript has an obvious dip in the period, hence, we need to give an explanation that the cloud appearance is responsible for the CBLH dip, and please the response to the next Comment.

27. Lines 269-270: “The influence of clouds on the CBLH is also reported in some earlier studies (Dewani et al., 2023; Bianco et al., 2022; Barlow et al., 2011).” Please explain more precisely how the clouds influence the CBLH.

Early studies from the Doppler lidar measurements reported the influence of low-level clouds (“Higher level clouds not detected by the lidar” in Barlow et al., 2011, and similarly, “This study considers the low clouds” in Dewani et al. 2023) on the CBL and turbulence.

In the revised manuscript, we rewrite the description as,

“In the MMCR observation, the CBLH shows a clear dip between 17:30 and 18:30, and then a lift as the clouds dissipates rapidly. Earlier studies from the Doppler lidar w investigated the complex influence of low-level clouds on the CBL and turbulence. The cloud-top radiative cooling drives top-down convective mixing, leading to the enhancement of σ_w^2 (Hogan et al., 2009; Harvey et al., 2013; Manninen et al., 2018). Whereas, during the warm season, the magnitude of σ_w^2 from the lidar w is large on clear-sky days and decreases on cloud-topped days, and the intensity of turbulence reduces with an increase in the cloud fraction within the CBL, except in the cloud layer that exceeds 90% of the CBL thickness (Dewani et al., 2023). Here, the cirrus clouds are above 11 km, thus the cloud-top driven convective mixing has little impact on the low atmosphere, however, the thick clouds cool the surface by attenuating solar radiation, which can weaken the surface-driven convective mixing. Therefore, the thick cirrus makes a large contribution to the CBLH dip.”

28. Line 271: What do authors refer to here when they say “subsidence”? Because subsidence is usually understood as a large scale process that implies synoptic stable conditions and it is not clear what this has to do with the CBLH subsidence. Do authors want to talk about a contraction or a decayment? That is not the same as subsidence.

Sorry for the unclear expression. “subsidence” is replaced with “dip”.

29. 277: The authors mention the 3 days that were selected, however there is no explanation for making this selection, please include a reason that explains this and hopefully validates that the comparison of different methods for estimating CBLH during these days is relevant.

We hope to use the chosen four cases for investigating the CBLH evolution in four seasons, and also for confirming these methods.

In the revision, we have added the sentence as

“The three days, without clouds and precipitation, are chosen as the representative in different seasons.”

30. Line 279: “It is very cold in January at..” In this case “very cold” results rather subjective, so please say how cold or in comparison to what.

This sentence is rephrased as “January is the coldest month of the year, and on 31 January, the minimum (maximum) temperature is -5 °C (4 °C) recorded in the weather forecast.”

31. 283: “Thereafter, the top of CBL ~~climbs~~ escalates quickly to..”

“climbs” is corrected to be “escalates”.

32. Lines 287- 289: “This implies that a moderately smaller threshold may be appropriate for the estimation of CBLH in winter with weak turbulence...” Following the discussion before, I don’t see the argument for this implication. Authors need to clarify this. Do they trust more on the RCS? And why? What ABL physical mechanisms are the different methodologies reflecting? I find a lack of discussion here that needs to be better addressed.

As shown in the Response to the Comment 24, the threshold of $\sigma_w^2=0.3 \text{ m}^2 \text{ s}^{-2}$ is appropriate for the CBLH estimation at Wuhan. We rewrite the sentence as follows, “it can be seen from Figure 6d that all the CBLHs from the lidar RCS are slightly larger than those from the MMCR σ_w^2 , which may be attributed to the long time-mixing aerosols and wet surface in winter.”

33. Lines 301-302: “In spring, sandstorms occur frequently in the northwest of China, and sand and dust with different intensities are often blown to Wuhan” Is there any particular interest in studying dust storms in spring? Is there any relationship for instance with the amount of dust and the resulting RCS or backscatter that the authors could analyze the impacts? Does that make any difference for the retrievals and their comparison during spring?

We are not particular interested in the study of dust storms in spring. However, the sand and dust are very frequent in spring, thus there are almost always strong or weak (and single or multiple layers) sand and dust in the lidar data in spring. The lidar observation is sensitive to sand and dust, which have a large influence of CBLH estimation from the

lidar RCS, as shown in the statistic results in Figures S3 and S4.

Hence, when we compare the spring results of MMCR and lidar, we cannot explain their differences if sand and dust is not mentioned.

In the revised manuscript, “In spring, sandstorms occur frequently in the northwest of China, and sand and dust with different intensities are often blown to Wuhan.” is rewritten to be,

“In spring, sand and dust with different intensities from the northwest of China pass frequently through Wuhan.”

34. Line 316: “lidar measurement ~~but through~~ utilizing the VV change in the time domain”

The word is changed in the revised manuscript.

35. Line 318: “of aerosol residual layer, the CBL tops from the MMCR and lidar ~~observations~~ CBLH retrievals are in good agreement with”

The sentence is rephrased as “the MMCR CBLHs are generally in agreement with the lidar CBLHs.”

36. Line 321: “Hence, the MMCR VV observation can capture the CBLH evolution very well under a...” Why do authors state that CBLH evolution is “very well” captured? This term sounds subjective and there is a lack of explanation of what do they mean by that.

This sentence has been rewritten as “Hence, the MMCR observation can accurately retrieve the CBLH and capture its diurnal evolution, especially for the CBL in the blind range of lidar.”

37. Line 323: What do authors refer to “seasonal characteristics of convection”? That needs to be clarified. Convection can be related to more larger-scale processes and stable or unstable tropospheric conditions that may or may not include humidity; which usually also implies a seasonality that is not mentioned here. Or it can be more related to radiative driven diurnal cycle convection and then it also can have a seasonality related to variations of radiation through the

year, but that is also not explained. Furthermore on that same line, it is not clear why a “slightly smaller threshold may be more suitable”. Please explain why.

Considering that the monthly and seasonal characteristics are investigated in the next section 5, these sentences are deleted in the paragraph.

38. Line 331: “~~Routinely, winter covers December, January, and February, and so on. We consider that winter covers the months of December, January and February, while March, April and May are spring, June, July and August are summer and the rest is autumn~~”

This sentence has been changed in the revised manuscript.

39. Line 333: “As we expected,..”

“As we expect” is corrected as “As we expected”

40. Line 334: “As the spot of direct sunlight slowly moves northward, the mean variance gradually increases” While looking at the figure, it is clear that not only the intensity of the variance increases but also and more importantly, the height up to which these large values are reached also increases, as well as the time duration of them. These facts should be included in the current analysis.

We agree with your suggestion. And we add the description as “moreover, the coverage height and time duration of its large values show an analogous monthly variation.”

41. Line 335: “... August, and then decreases ~~step by step~~ gradually...”

“step by step” has been replaced with “gradually”.

42. Line 336: “variance is significantly larger in spring than in autumn” Please be more specific, here you could add some numbers.

This sentence has been changed as

“the variance is significantly larger in spring than in autumn. Not only the maximum CBLH of 1.14 km at 13:30 in spring is much higher than that of about 0.66 km at 13:30

and 14:00 in autumn, but also the mean σ_w^2 of $0.42 \text{ m}^2 \text{ s}^{-2}$ in the CBL during spring is stronger than that of $0.35 \text{ m}^2 \text{ s}^{-2}$ during autumn.”

43. Lines 336 and 337: “ These monthly and seasonal features of convectively driven turbulence dominate the evolution of monthly and seasonal mean CBLHs.” This is a sentence with high repetitiveness and not really with any information, please re-write it or don’t include it.

According to your suggestion, this sentence is removed in the revision.

44. Lines 342-345: Authors analyze figure 10, where maximum value of CBLH is presented for the 12 months. However it is not clear why is this maximum value chosen and there is a lack of analysis on the seasonality that this data implies. Furthermore, figure 10 also shows the local time when these maximum values were reached but this is not further analyzed nor explained, what does it imply? Then They start a sentence on line 344 saying “In weather forecast record there are 7,3,13,3 and 0 days with moderate to heavy rain...” But there is a lacking of a connecting sentence that connects this idea with the one in the previous sentence. Why are authors addressing heavy rain here? What do these numbers mean?

As you said, the monthly and seasonal mean CBLHs are presented in Figure 9, and their maximum heights are chosen as Figure 10, which is repetitive. Hence, Figure 10 is deleted in the revised manuscript.

45. Lines 351-357: “ As shown in Figure 9, the CBLH in July has the largest standard deviation (between 13:00 and 19:00) and the latest occurrence time of maximum value over the whole year, which is possibly attributable to the cloudy and rainy weather in addition to the strongest radiation. Similarly, the variability of weather conditions may be a major reason why the maximum height arises 1-2 hours earlier in April-June than in March. Nevertheless, with the gradual decline of solar radiation, the occurrence time of maximum height is steadily advanced from 17:30 in July to 13:00 in November and December.” This explanation about figure 9 should be before in the Manuscript, before talking about figure 10, please move it and make it consistent.

Figures 10 is deleted, and the relevant description is shifted to the explanation about figure 9.

46. Lines 363-368: “ The occurrence time of averaged maximum CBLH is the earliest at about 12:40 in December and the latest at 15:45 in August, which is slightly distinguished from those in the maximum value of mean CBLH. The standard deviation of occurrence time is obviously large in January, July and September. These results imply that the maximum height and its occurrence time of daily CBL are significantly influenced by the weather conditions besides radiation since the VV variance as a proxy of convectively driven turbulence is sensitive to the weather changes.” These lines first are purely descriptive but I don’t see any elucidating analysis on how this maximum CBLH at different times during different months are showing any new information. Again there is a lack of discussion about the processes that can be responsible for those variations. And when the authors mention the “weather conditions” they should be more specific i which conditions are they referring to and how do they change seasonally. Please re-write this making a valuable physical analysis or maybe even don’t use the plots on figure 10 if they don’t have any conclusive fact about it.

We agree with your comment. Indeed, Figures 10 and 11 come from Figure 9, and do not provide more new information, and are removed in the revision.

In particular, the retrieved CBLH is dominated by the surface heating associated with solar radiation, and is also significantly impacted by many factors, such as air humidity, ground moisture, clouds within the CBL and clouds topped the CBL, mid- and high-level clouds, and even sand and dust. Because of this, the CBLH may also display a large change from day to day even in a same month. Hence, it is relatively easy for a case in a specific day to clarify the influence of weather conditions on the CBLH. In the statistical analysis, the effects of weather conditions require lots of detailed weather data that we lack. To focus on the purpose, Figures 10 and 11 are deleted.

47. Lines 371-373: “ In this study, we investigate the diurnal evolution of monthly and seasonal mean CBLH at Wuhan by the VV variance method based on the Ka-band MMCR observation,

and compare the CBLH evolution with that by the RCS gradient, variance and wavelet methods from the lidar measurement.” You should add a sentence mentioning that also some study cases were investigated and why those particular study cases; how do they relate to your findings.

According to your suggestion, we add the description in Summary, as follows,

“Although the RCS is proportional to aerosol concentration and w represents the vertical motion of aerosol particles, the comparison of four examples in different seasons indicates that the CBLHs from the MMCR w are in good agreement with those from the lidar RCS, except for the initial growth and final decay phases. The discrepancy can mainly be attributed to the aerosol residual layer and the lidar blind range. The influence of residual layer on the lidar RCS generally causes an overestimation of CBLH, meanwhile, it is impossible for lidar to capture the CBL top within its large blind range. In addition, the CBLH in the MMCR observation shows less contamination by the long-range transport of sand and dust, and thick high-level clouds due to the rapid response of aerosol w relative to its concentration. In this case, the MMCR observation can capture the diurnal evolution of CBLH.”

48. Line 374: Be more specific when saying “statistically analyze” what do authors refer to by that?

“we statistically analyze the monthly and seasonal variations of CBLH.” is rephrased as “we investigate the evolution of monthly and seasonal mean CBLHs”.

49. Lines 379-381: “The occurrence times is between 13:00 in November and December and 17:30 in July for the maximum value of monthly mean CBLH, but between about 12:40 in December and 15:45 in August for the monthly mean value of daily maximum CBLH, respectively.” Authors should explain why are they investigating these times and specifically mentioning them even in the summary. I don’t see any clear elucidating analysis about these times.

As Figures 10 and 11 are removed, the sentence is deleted in the revision.

50. Line 382: “~~feature~~ behavior, the seasonal mean CBLH has the maximum heights of 1.29 km at 14:30 and 15:00 in summer, 1.14”

“feature” has been replaced with “behavior”.

51. Lines 383-384: “These results are similar to those in earlier studies...” Similar in what sense? The variables, seasons, comparison between methodologies and its particular characteristics or some more objective facts need to be specified in this sentence. Also maybe it is worth mentioning the influence of different terrain, latitudes, synoptic conditions. How is this comparable?

According to your suggestion, we make a careful comparison, which is moved to Section 5, as follows,

“In previous studies, based on the threshold of σ_w^2 from the Doppler lidar measurement in Mexico City (19.3° N, 99.1° E), the CBLH is higher in spring and summer, and lower in winter, while the maximum CBLH of about 1.5 km occurs in May, which is because the CBLH is suppressed to some extent by increased cloud cover in the rainy season between June and September (Burgos-Cuevas et al., 2021). However, the CBLH retrieved from the ceilometer backscatter data is obviously larger than that from the threshold of σ_w^2 (Burgos-Cuevas et al., 2021; Tang et al., 2016). Similarly, in the estimation of CBLH from the lidar RCS over Wuhan and Granada (37.18° N, 3.60° E), the maximum values of seasonal mean CBLHs in all the seasons are larger than those in our results although the gradual ascent of CBLH from winter and autumn to spring and summer is consistent with that in our results (Kong and Yi, 2015; Granados-Muñoz et al., 2012).”

52. Lines 391-392: “...the CBLH from the lidar RCS is higher than from the MMCR VV variance, due to the high blind range of lidar and the strong influence of aerosol residual layer on the lidar RCS.” It is not clear why is this due to the high blind range of lidar. Please explain further.

The description is rewritten as “it is impossible for lidar to capture the CBL top within

its large blind range.”

53. Line 395: “Additionally, in comparison to the lidar RCS affected by the history of aerosol mixing processes, the CBLH” It is not clear how are the authors attributing this to the history of aerosol mixing processes. Please address it more specifically.

It should be “the change of aerosol concentration lags behind the variation of its vertical velocity”. Because of the comparison is move to the second paragraph, “Additionally, in comparison to the lidar RCS affected by the history of aerosol mixing processes” is removed in the revised manuscript.

54. Line 407: Please specify what “weather conditions” in particular are the authors referring to. They should include maybe how was temperature, pressure, humidity, was there rain? How were the synoptic conditions on the investigated days. This implies that the authors may need to consider more information and make extra plots showing this or justifying it in a different manner.

We agree fully with your suggestion. The weather conditions mean to consider more information and make extra plots. The sentence is deleted, and the revised manuscript is more focused relative to our previous one. Finally, we really appreciate your many valuable comments and suggestions on our manuscript, again.