Response to Referee 2,

We sincerely thank 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.

Major comments:

1. Too many expressions are used to describe the planetary boundary layer (PBL) in this manuscript, including boundary layer, boundary, CBLH. The PBL can be basically divided into convective boundary layer, neutral boundary layer and stable boundary layer, according the atmospheric static conditions. Therefore, one of my greatest concern is the topic of this work is the evolution of CBL height based on the measurements from MMCR. To my knowledge, the determination of CBL needs the temperature profiles. But I can not see any such profiles in the retrieval process of CBL height.

Sorry for our unclear expression. In the revised manuscript, only the PBL and CBL are presented, and the other expressions are changed.

We fully agree with you that the determination of CBL needs the temperature profiles. As you know, it is difficult to obtain the temperature profiles with high temporal resolution, thus we cannot compare the diurnal evolution of CBLH from the temperature measurement with that from the MMCR observation. Here, we compare the CBLH from the MMCR vertical velocity with that from the temperature in the routine radiosonde observation. The radiosonde is routinely released in Wuhan at 8:00 LT and 20:00 LT. The sun has gone down at 20:00, thus we present the comparison at 8:00.

The radiosonde data are provided by University of Wyoming at the website of https://weather.uwyo.edu/upperair/bufrraob.shtml. The Radiosonde data in 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 about tens to hundreds of meters in the thousands of meters above the surface. Thus, we choose some days without precipitation in the second half of 2021.

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 S1 (only presented in the Response) shows the comparison of CBLHs derived from the three methods at 8:00 in some days.

As shown in Figure S1, the CBLH from the threshold of σ_w^2 from MMCR is generally consistent with the CBLHs from the gradient of θ and the threshold of bulk Ri from radiosonde, which indicates that the MMCR measurement can be used to estimate the CBLH in Wuhan.

Nevertheless, there is also a little difference in the results from the three methods, which is mainly because these methods have the different physical principles and mathematical algorithms. Similarly, a little difference can be seen in the CBLHs derived from an identical variable of lidar RCS by three methods.

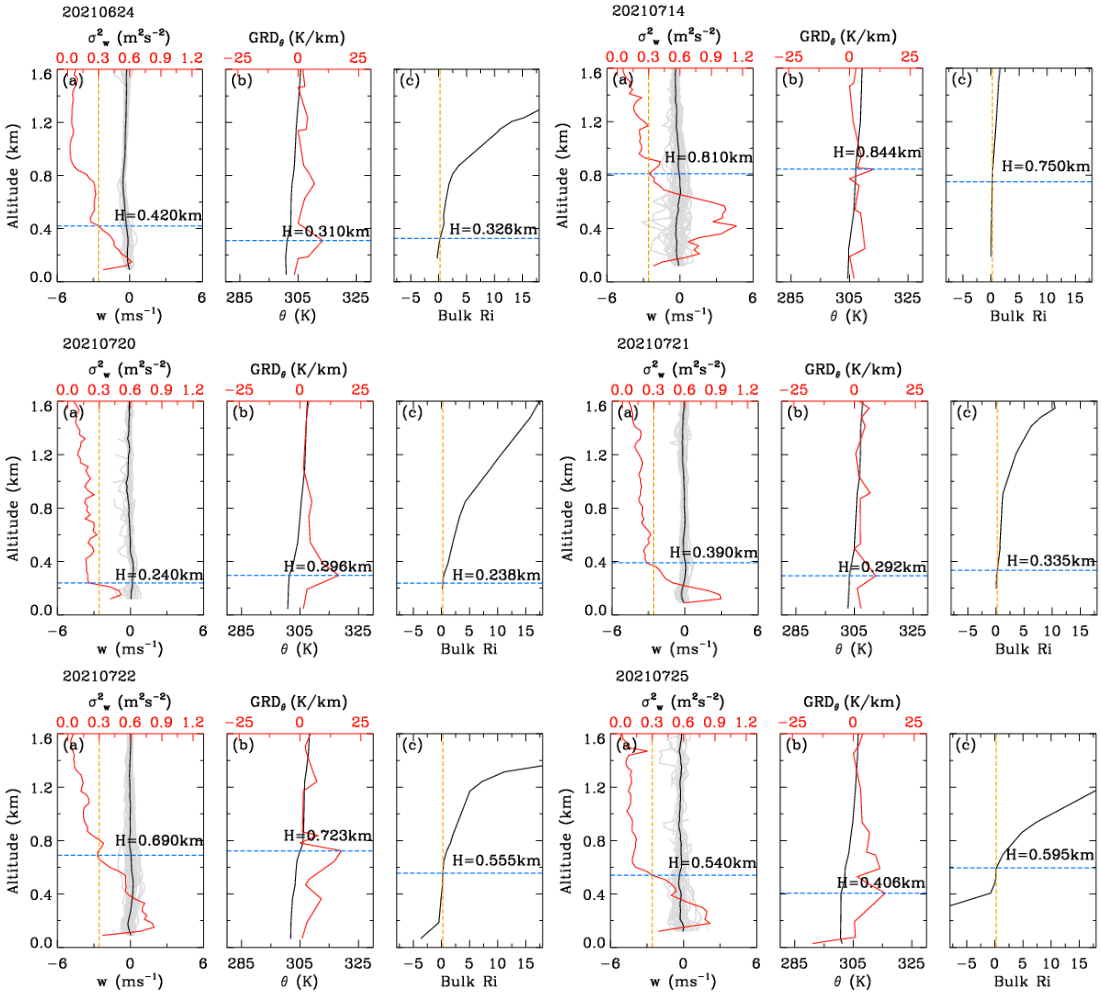

Figure S1. Comparison of CBLHs estimated by the threshold of σ_w^2 from MMCR, and the maximum gradient of θ and threshold of Bulk Ri from radiosonde data at 8:00. There are the three panels in each day, and the blue horizontal line denotes the position of estimated CBL top. In the panel (a), the gray thin and black thick lines denote the vertical velocity and their mean values from MMCR, respectively; the red line denote σ_w^2; and the yellow line denotes the threshold of σ_w^2=0.3 m^2 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.

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.

In the revised manuscript, we add the sentence as follows,

"By comparison (not presented), the CBLH at 8:00 derived from the threshold of σ_w^2 =0.3 $m^2 s^{-2}$ 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 σ_w^2 =0.3 $m^2 s^{-2}$ is appropriate for the CBLH estimation at Wuhan."

2. My second concern lies with the physical basis for the PBL height retrieval from MMCR. As the authors stated in the Introduction section, "there are few reports on the use of vertical velocity obtained from Doppler cloud radar for the CBL investigations." To the best of my knowledge, the cloud-topped PBL is extremely complex due to the complicated turbulence-convection interaction, and the entrainment/detrainment process near the cloud edges. Nevertheless, the MMCR can not efficiently obtain any information (e.g., the vertical velocity) in the absence of cloud, which exactly corresponds to the cloud-topped PBL. Even though the authors say that there exists a weak echo layer near the surface, this could be due to the clutters. If not, the PBL top is well above the near surface layer. Then I pose a question "what is the physical basis for the CBLH and how reliable?"

We think that this is a very good question, and we also thought about the question of physical basis carefully before we did the work. We would like to explain it from the following aspects.

Firstly, conventional microwave radar is pulse radar, and the MMCR in our work is a frequency-modulated continuous wave (FMCW) radar. Due to the continuous transmitting and receiving, the FMCW 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.

Secondly, we analyze the FMCW radar sensitivity, which refers to the minimum reflectivity detected by radar at a certain altitude. We calculate the radar sensitivity according to the radar equation, which is shown in Figure S2, together with the distribution of reflectivity from the MMCR observation in June 2020. The number of reflectivity count is within the bin of 30-m height (a radar range gate) and 1-dBZ reflectivity. The minimum detectable reflectivities at different heights are close to the calculated value, indicating the fine performance of MMCR.

The high occurrence rate of reflectivity between -40 and -60 dBZ below 2.5 km is due to various large aerosol particles, including low-level cloud particles (Browning and Atlas, 1966; Chandra et al., 2010; Moran et al., 1998; Zhang et al., 2024).

We calculate the total number of reflectivity count at each radar range gate (30 m height) in June 2020, which is shown in Figure S3. Below about 1.8 km, the total number at each height is more than 4.3×10^4, approximately equal to 4.32×10^4 (June has $60\times24\times31=4.32\times10^4$ min). The MMCR has a 5-min self-check every day, which indicates no recorded data for 155 min in June. Hence, this means that there always exists echo signal below 1.8 km in June. The low-level clouds from the surface to 1.8 km cannot occur throughout June, thus the weak echoes from the surface to about 1.8 km come mainly from the backscattering of various large aerosol particles, including low-level cloud particles.

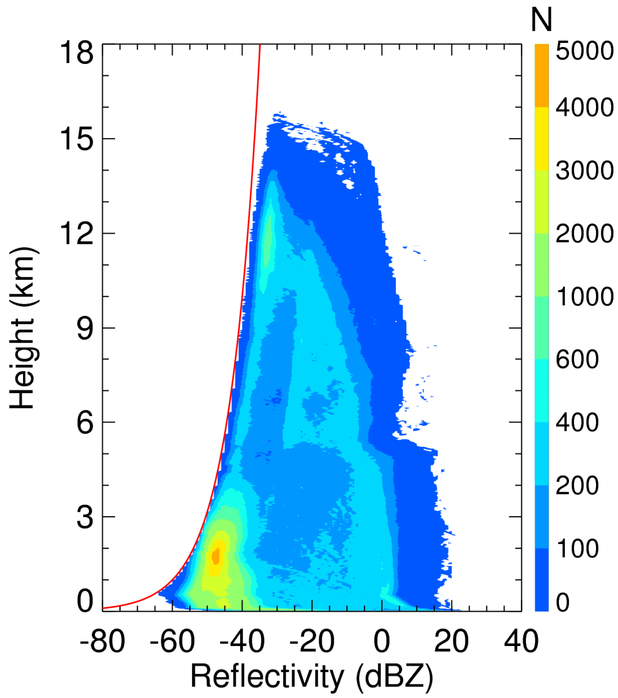

Figure S2. (red line) Sensitivity calculated vs. (color shading) statistical number of reflectivity from MMCR observation in June 2020.

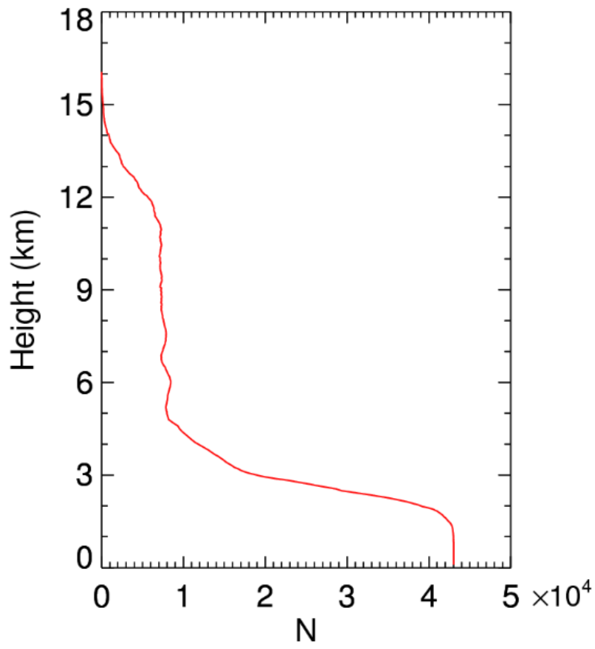

Figure S3. Total number of reflectivity count from MMCR observation in June 2020.

Thirdly, in previous studies, the weak echoes near the surface are attributed to the backscattering of small insects and aerial plankton in some studies (Franck et al., 2021; Chandra et al., 2010; Achtemeier, 1991), and are also suggested to come from the scattering of dust particles in other studies (Görsdorf et al., 2015; Clothiaux et al, 2000; Moran et al., 1998).

Aerosol particles typically range in size from 0.01 to 10 μm, with floating dust particles occasionally reaching 10 μm in diameter. Smoke particles are typically less than 1 μm in size, while plant aerosols range in size from 5 to 100 μm, and combustion-generated aerosols exhibit a particle size of 0.01 to 1000 μm. For cloud particles with diameter D=10 μm, the number concentration of 100 cm^{-3} have a reflectivity factor of Z= -40 dBZ. Assuming a same dielectric constant, a reflectivity factor of Z= -50 dBZ corresponds to the number concentration of 10 cm^{-3} for D=10 μm aerosol particles. Therefore, considering that there are lots of larger aerosol particles in the lower atmosphere, for example, dust particles visible to the eyes in the sunlight coming in through the window, various large aerosol particles (including not only low-level cloud particles, but also plant aerosol particles, dust particles, and all kinds of urban emission particles) can cause a very weak reflectivity (-60 to -40 dBZ) in the MMCR observation, as shown in the statistical result from Figure S2, in other words, the MMCR can obtain the reflectivity and vertical velocity information through aerosol particle backscattering in the absence of low-level clouds.

Finally, as you said, the cloud-topped PBL is extremely complex due to the complicated turbulence-convection interaction, and the entrainment/detrainment process near the cloud edges. We present three examples of clouds in Figures S4-S6. There are mainly the low-level (cloud-topped), mid-level and high clouds in Figures S4, S5 and S6. In all three cases, the CBLH can be identified by the vertical velocity variance, moreover, the clouds in different heights have the influence on the CBLH. There are the complicated dynamic processes involved in the interaction between the PBL and the clouds, thus the MMCR observation provides an effective means to explore these complex processes since the MMCR is a powerful instrument for observing clouds and weak precipitation, and this is also what we will continue to strive for in the future.

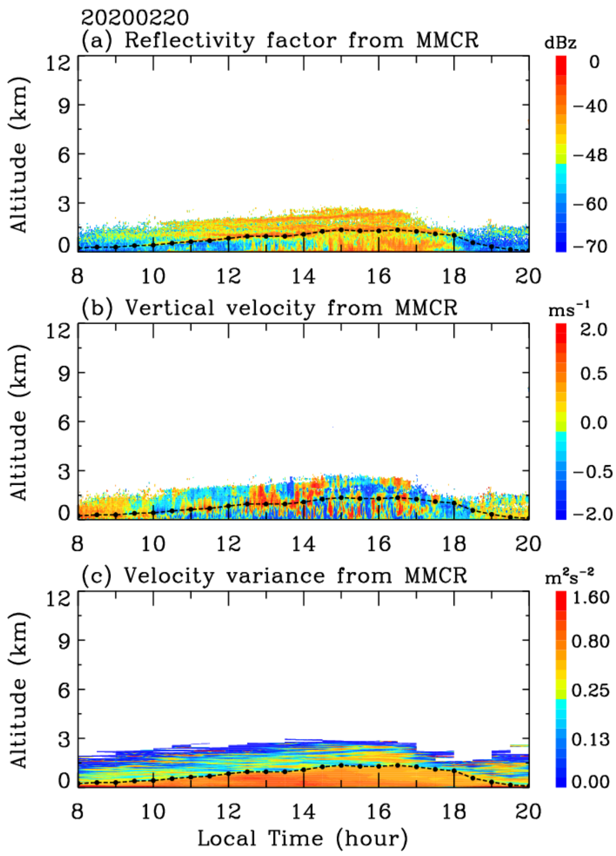

Figure S4. (a) Reflectivity, (b) vertical velocity and (c) vertical velocity variance from MMCR observation on 20 February 2020. The black line denotes the identified CBLH.

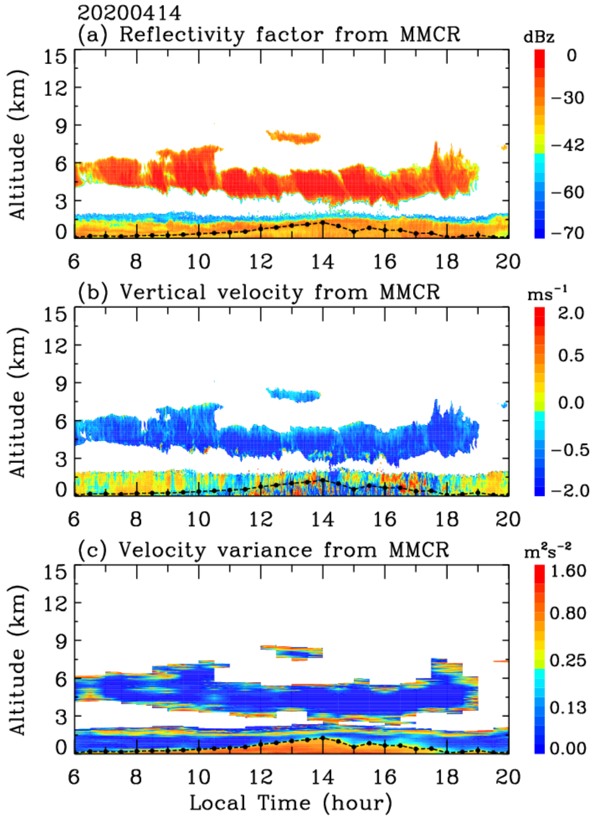

Figure S5. Same as Figure S4 but for 14 April 2020.

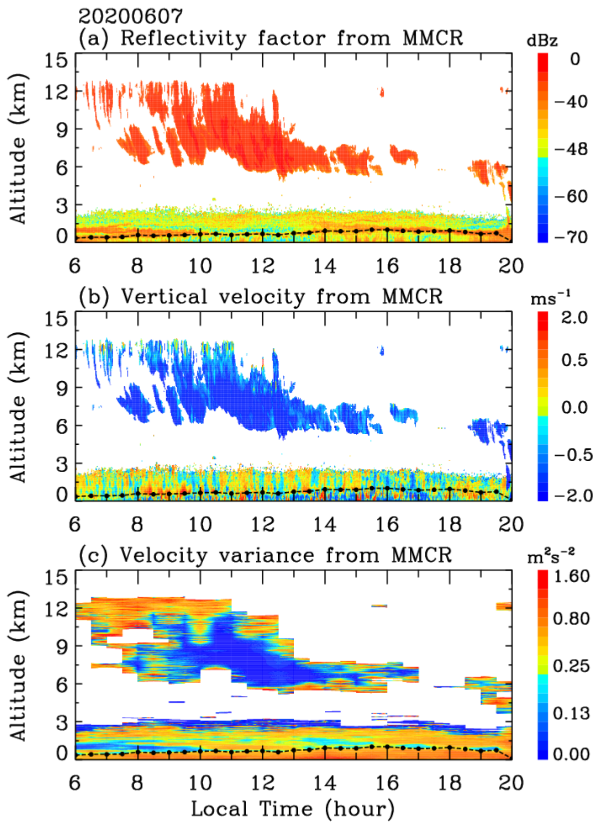

Figure S6. Same as Figure S4 but for 7 June 2020.

Specific comments:

1. Lines50-51: it is totally wrong to state that “In the afternoon, ***turbulent activity is weakened”. Conversely, in the absence of cloud or synoptic-scale weather system, the turbulence tends to reach the maximum, due to the strongest sensible heat flux in the afternoon.

We agree fully with you. It should be “In the late afternoon”. Combing your suggestion with that from the other Referee, this sentence is corrected in the revision as,

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

2. Lines 51-52: Except for the existence of aerosol particles in the residual layer, most of them are present in the nocturnal stable PBL.

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

“most of aerosol particles within the CBL are deposited into the nocturnal stable PBL due to the rapid weakening of convectively driven turbulence, and some particles are transformed into an aerosol residual layer.”

3. Line 68: What is the “the boundary top”? is it different from the atmospheric boundary layer top? If not, why not use the same term throughout the whole manuscript?

“the boundary top” is changed as “the CBL top”.

According to your helpful suggestion, the boundary layer (top or height) in the manuscript is concretized as the PBL or CBL (top or height).

4. Lines 76-77: “The radiosonde data have a widely geographical distribution and long-term accumulation” should be rephrased.

Combing the other Referee’ suggestion, we delete this sentence in the revised manuscript.

5. Line 78: “boundary layer” refers to “planetary boundary layer height ()”?? if so, what are the difference between PBLH and CBLH?

In this paragraph, “boundary layer (height)” is reworded as “CBL (CBLH)”.

6. Line 92-96: Too long sentence for “Wind profile radar can … turbulence (Liu et al., 2020…” and thus I suggest to rephrase it.

In the revision, the sentence is divided into two sentences, as follows,

“The vertical gradients in temperature, humidity and turbulence change the profile of atmospheric refractive index, which can cause the scattering of electromagnetic waves. Wind profile radar obtains the atmospheric wind speed and direction by decomposing the Doppler shift of backscattered waves.”

7. Line 109: I do not understand the meaning of “Plunge”.

In the revised manuscript, “by tracing the height of aerosol concentration plunge” is changed to be,

“by tracing the height where the aerosol concentration sharply decreases with height.”

8. Line 114: “capability” -> “incapability”

“limited by the ability of lasers to penetrate clouds” is corrected as “due to the incapability of lasers to penetrate clouds”.

9. Line 121: Is there a rapid decline stage of CBL in the afternoon?? If so, some necessary references are needed to be provided here.

Sorry for our unclear description. “the rapid decline stage of CBL in the afternoon” is addressed to be,

“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)”.

10. Line 123: Please elaborate on the definition of “historic effect”.

In the revised manuscript, “This discrepancy often reflects the historical effect of aerosol mixing rather than the current situation of convectively driven turbulence” is rephrased to be,

“This discrepancy is due to aerosols from a long time-mixing process rather than the current situation of convectively driven turbulence”.

11. Language: There are too many grammar errors or inappropriate expression throughout the whole manuscript. I can not continue the reviewing processes if the authors did not seek help from a native English editor or colleague.

According to your constructive suggestion, we have conducted a thorough review of the paper and sought assistance from English-speaking colleagues to correct grammatical errors and improve expressions. And we thank you very much for your valuable comments and suggestions on our manuscript, again.