Response to Editor

Dear Editor & Prof.

We greatly thank you and the reviewer for the thorough and valuable suggestions to our work. According to the reviewer' concerns, all of the comments have been reponded point to point as shown below and the manuscript has been revised accordingly. We believe that the quality of the manuscript has been promoted now.

We would like to resubmit the revised manuscript together with this response letter. The authors hope that the updated work can meet the requirement of **Atmospheric Measurement Techniques.**

Thank you very much for considering our work!

Yours sincerely,

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General comments:

This manuscript presents an observational combined lidar (1064 nm) and radar (8.6 mm) data set to determine the cloud boundaries over the ground station located at the Xian region. The authors use signal enhancement techniques to avoid background and aerosol signal thereby improving the SNR for the identification of cloud top and base boundaries. Analysis of one-year data set over the Xian is presented characterizing the cloud cover and single/multiple cloud layer occurrences. Overall, this is an interesting manuscript and has the potential to be published.

We appreciate the reviewer's thoughtful review and constructive comments, which have greatly helped to enrich the details and improve the quality of the paper. These comments have been revised and supplemented in the manuscript, and the responses to each comment are given below. The manuscript has been polished and modified by professional organizations, and I believe that English has been greatly improved.

1. It is well established that combined lidar and radar measurements are essential to monitor the local cloud cycle. This is also acknowledged by the authors here in the manuscript with some references (Line 76) and demonstrated with few case studies (section 4.1). However, the one-year data presented here do not have simultaneous measurements from lidar and radar for about one-third of the total time (7248 hours). This could introduce bias: (a) in the cloud base boundaries as also shown in fig 10 (19:00 – 00:00 hrs) for the cases of cirrus to altostratus transition where the cloud particles would eventually grow into large sizes producing precipitation, and (b) in cloud top boundaries where the ice crystals are too small to be detected by the radar (fig 10, 19:00 – 20:00 hrs). This bias should be mentioned in the abstract and needs to be discussed in the main text.

Response: As discussed and analyzed in Section 4.1, MMCR can effectively measure cloud tops compared, but it has no advantage over lidar in detecting cloud bottom. We analyzed the correlation of cloud bottom (0.803) between obtained by MMCR after data control and detected by lidar, and considered that the two instruments have a high correlation for the detection of cloud bottom height. Therefore, we used MMCR data (7248 hours) aided by lidar data (872.5 hours) to improve the accuracy of cloud bottom detection. To reduce the error caused by directly employing MMCR to analyze the cloud bottom. Two biases (a) and (b) have been added to the abstract and discussed in the main text.

Specific modifications are as follows:

1) L 12-L 17:

We analyzed three typical cases (e.g., single-layer clouds, multilayer clouds, and precipitating clouds), case one presents two interesting phenomena: a) at 19:00~20:00, the ice crystal particles at the cloud top boundary are too small to be detected by MMCR, which is well detected by lidar. b) at 19:00~00:00, the cirrus cloud transits to the altostratus where the cloud particles would eventually grow into large sizes producing precipitation，and MMCR has more advantages than lidar in detecting the cloud top boundary within this period.

2) L 248-L 254:

At 19:00 ~ 20:00, in cloud top boundaries where the ice crystals are too small to be detected by the MMCR, but the lidar detects the real cloud top. The main reason is that the echo intensity of MMCR is proportional to the 6th power of particle diameter, and the lidar echo signal is proportional to the square of particles. From 19:00 to 00:00, the cirrus cloud transits to the altostratus cloud, where the cloud particle size increases in the form of collision and finally produce precipitation. In this process, the lidar beam entering the cloud is attenuated, but MMCR has a good advantage in cloud top detection.

2. I suggest including the lidar wavelength or spectral region in the title (and abstract) of the manuscript, since this often gives the impression that lidar is operated at visible channel (532 nm) – if specific wavelength or type of instrument is not mentioned. Further the term ‘statistical analysis’ in the title is misleading. To my understanding there is no statistical analysis in this manuscript, rather the authors just present the frequency of cloud top/base altitude occurrences and its seasonal variability.

Response: We changed the title of the manuscript to “Detection and analysis of cloud boundary in Xi’an, China employing 35 GHz cloud radar aided by1064nm lidar”

3. Extensive editing of the manuscript is required for the proper English usage.

Response: The manuscript has been polished and revised by professional institutions.

Specific Comments:

1. L 49: 'Pal et al' is repeated. There are several instances throughout the manuscript where the citations embedded in the sentence has repeated words.

Answer: We have modified all the similar situations in manuscript, as follows:

1) L 49 'The differential zero-crossing method proposed by Pal et al. (Pal et al.,1992)' is changed to ' The differential zero-crossing method proposed by Pal et al. (1992)'

2) L58 'Morille et al. (Morille et al., 2007) determined the local maxima on both sides of the cloud peak as the cloud…' is changed to ' Morille et al. (2007) determined the local maxima on both sides of the cloud peak as the cloud'

3) L 60 'underestimated, respectively. Mao Feiyue (Mao et al., 2011)' is changed to ' underestimated, respectively. Mao Feiyue (2011)

4) L65 'Kollias et al. (Kollias et al., 2007) judged the SNR value' is changed to 'Kollias et al. (2007) judged the SNR value'

5) L67 'Clothiaux et al. (Clothiaux et al.,1999) used 35 GHz millimeter wave cloud measuring radar' is changed to 'Clothiaux et al. (1999) used 35 GHz millimeter wave cloud measuring radar'

6) L170 'Referring to the empirical formula proposed by Riddle (Riddle et al., 1989)' is changed to 'Referring to the empirical formula proposed by Riddle (1989) '

7) L379 'Zhao et al. (Zhao et al., 2014) at the SGP site and Hailing Xie (Xie et al., 20217)' is changed to 'Zhao et al. (2014) at the SGP site and Hailing Xie (20217) '

2. L 115: Please use appropriate standard literature reference for the elastic backscattering lidar equation. For example: Measures, R.M., Laser remote sensing: Fundamentals and applications, Willey Publishers, 510 pp, 1984.

Answer: The reference 'Laser remote sensing: Fundamentals and applications, Willey Publishers, 510 pp, 1984' does not point out the standard lidar equation, so we refer to the standard radar equation in the reference 'Wandinger U.: Introduction to Lidar, Brooks/Cole Pub Co, doi:10.1007/0-387-25101-4_1, 2005.' as follows

$$P(\lambda,r)=P_0\frac{c\tau}{2}A\eta\frac{O(r)}{r^2}\beta(\lambda,r)\cdot\exp\left[-2\int_0^r\sigma(\lambda,r)dr\right]. \qquad (1)$$

where λ is the wavelength of the emitted light, r represents the detection distance, and $\beta(\lambda,r)$ and $\sigma(\lambda,r)$ are the atmospheric backscattering coefficient and atmospheric extinction coefficient, respectively. The $O(r)$ is the laser-beam receiver-field-of-view overlap function,

c is the speed of light, P_0 is the average power of a single laser pulse, τ is the temporal pulse length, η is the overall system efficiency, A is the area of the primary receiver optics responsible for the collection of backscattered light.

3. L 133: Details on the wavelet function used should be mentioned here.

Answer: See the answer 4 below.

4. L 135: Complete description of the flow chart processes – variables are missing. For example, the variables/symbols Rs, id, Pe, Ma, and Mi shown in figure 2 are nowhere defined.

Answer: L 133-137: 'Therefore, in this paper, we use the soft-threshold wavelet denoising method to process P_{new} (λ,r) to obtain P_{new_s} (λ,r). To avoid atmospheric turbulence and noise interference, P_{new_s} $(\lambda,r)$is processed in one step according to the algorithm flow in Fig. 2, and the enhanced signal P_{new_sp} (λ,r) is obtained, as shown in Fig. 3b) and Fig. 4b).' is changed to 'Therefore, the P_{new} (λ,r) is de-noised by wavelet transform, the threshold function is soft threshold, the wavelet base is sym7, and the number of decomposition layers is 5. According to flow chart 2, the P_{new_s} (λ,r) after the disturbance treatment from the front and the end, P_{new_s1} (λ,r) and P_{new_s2} (λ,r) are obtained respectively, and their average values are $P_{new\_sf}(\lambda,r)$. To $P_{new\_sf}(\lambda,r)$ carry out ascending arrangement, and record new sequence R_S and the corresponding index id. The maximum and minimum of R_S are denoted as Ma and Mi, respectively. Build new mapping proportion coefficient $Pe(i)$ the enhanced signal P_{new_sp} (λ,r) is obtained, as shown in Fig. 3b) and Fig. 4b).'

5. L 138: What about the cases when high level clouds exist? It is well known that cirrus types of clouds occur high in the troposphere extending to the tropopause (on average ~17 km during summer over the subtropics).

Answer: In line 138, the 15-20km height range used to fit the slope is applicable to Xi'an region (in the data of the past two years, there are few clouds higher than 12km). When there are high-level clouds, the range of slope fitting should be the echo signal above the high-level clouds

6. L 206: Do you mean the 2 min time-resolution lidar profiles are duplicated 24 times to make it look like 5 sec temporal resolution data? Please mention this clearly.

Answer: No, we perform linear interpolation on the lidar data within 2min, and keep its time-resolution consistent with MMCR, that is, the 2min one group of data becomes 2min 24 groups.

7. L 355: I don't think these are statistical rules. Please replace the term 'statistical rules' with 'logic-based' rules or something like that throughout the manuscript

Answer: L 355 'The statistical rules shown in Table 3' has been replaced by 'The cloud bottom height recording guideline in the Table3'. Other 'statistical rules' in the manuscript have been modified or replaced, and the specific details are given in the answer 15.

8. L 359: The case1 in Table 3, please be specific if you mean 'optically thin' or 'geometrical thin' cloud? If it is optically thin than both cloud top and base can unambiguously be determined from lidar.

Answer: L 359: 'Thin cloud' is changed to 'geometrical thin' cloud in Table 3.

9. L 376: Clouds above 8 km has highest frequency in autumn, and these are likely stratus and cumulus clouds? This sentence doesn't make any sense. Please refer to the WMO cloud classification – stratus and cumulus are low-level clouds those formed within 2 km above the surface level.

Answer: According to the expert opinion, we have re-defined the division of seasons (answer 12), so the observation data has been slightly adjusted, and the corresponding expression has changed. See the answer 10 below for details.

10. L 378: "height range of clouds is narrow, and the numerical range is wide"? Please re-write this sentence for more clarity mentioning the height range you are referring to.

Answer: For vertical distribution of cloud base, the first narrow peaks is boundary layer clouds (≤ 1.5 km) , and the second peak is 2.5 ~ 3.5 km, and the third peak has a big range in vertical height, which is around 4.7-10 km a in spring. Fig.18 b) expresses that the cloud bottom height in summer is mainly distributed at 3-9.5km, indicating that the middle and high cloud may be dominated. The distribution of cloud bottom shows the bimodal, the first peak is the boundary layer cloud peak, and the second peak is located at 2.7-3.7 km and 3.6-8.3 km in autumn and winter, respectively.

11. L 383: Why the data presented in the figures showing vertical distribution of frequency of cloud occurrences are limited to 12 km? Or is this an underestimation of cloud top boundaries owing to the sensitivity of 8.6 mm radar? It is not uncommon to have high level clouds extending up to 15 km or more in the region of interest. Please present the results upto the tropopause level.

Answer: In July, 2021, the detection distance base of MMCR increased from 420 to 600, that is, the maximum detection range increased from 12.6km to 18km. We checked the echo data of MMCR (the maximum detection range is 18km) for 199 days one by one. Among them, only one day's data show that cirrus clouds existed at about 13km, and only four days' data show that the cloud top was slightly more than 12km. Therefore, our analysis of cloud boundary is limited to 12km. At the same time, we have added the specific time when the maximum detection range of MMCR changes in the manuscript. Add description as 'During the 12-month observation, the maximum detection range of MMCR has changed.

From December 2020 to June 2021, the maximum detection range of MMCR is 12.6km, and then the maximum detection height is changed to 18km.'

12. L 390: Before discussing the result, it would be beneficial to briefly describe how normalized cloud cover is computed here. Also, indicate the months of the season – spring (MAM), and summer (JJA). How is the maximum cloud cover 2.46 in summer?

Answer: L 356-358 'The experimental data of 302 days (65 days in spring (January-March), 84 days in summer (April-June), 65 days in autumn (July-September) and 88 days in winter (October-December) observed in 2021 are classified and sorted out to ease the statistics and analysis of the variation characteristics of cloud boundary height', which is no solar term to define the season, so we re-describe it as 'From December 2020 to November 2021, MMCR and lidar store 302 days (7248 hours) and 126 days (872.5 hours) of observation data, respectively. The total observation hours of MMCR and lidar in each month are shown in Fig. 17 (in answer 15). The hours of lidar, MMCR and simultaneous measurements is 872.5 hours. In this paper, the four seasons are defined as spring from March to May (MAM), summer from June to August (JJA), autumn from September to November (SON) and winter from December to February (DJF).' So the monthly cloud layer frequency and cloud cover are re-drawn as shown in Fig.19.

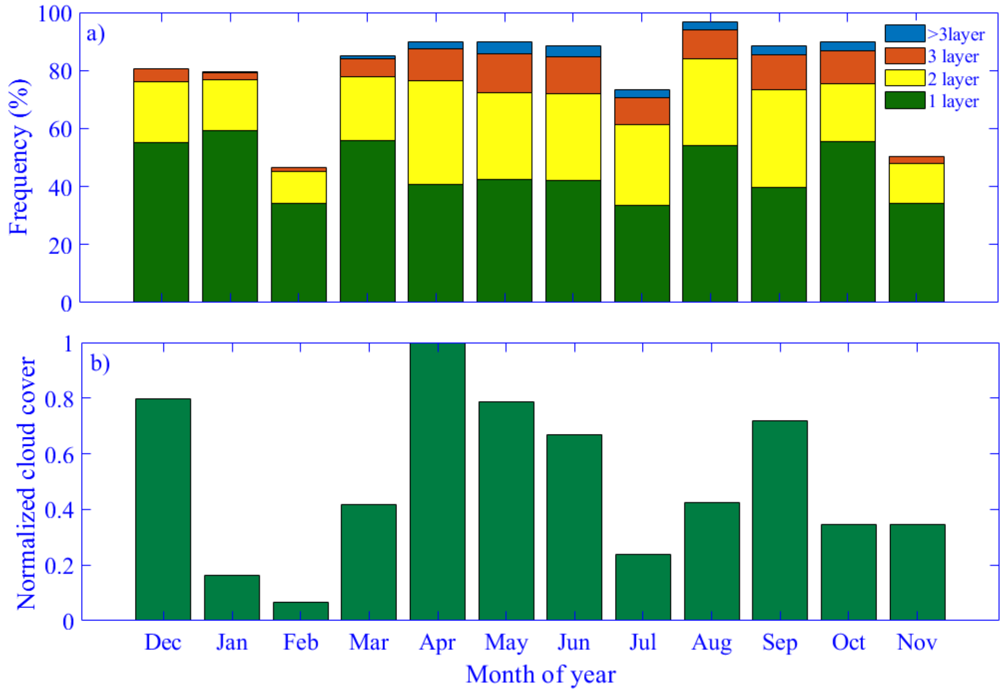

Fig. 19 The monthly variation in cloud frequency distribution and cloud cover from December 2020 to November 2021 a) monthly variation in the frequency of the number of cloud layers. b) monthly variation in cloud cover

MMCR defines cloud cover as the percentage of cloud obscuring sky field of vision. Cloud cover observation includes total, low, medium and high cloud cover. Total cloud cover refers to the total number of cloud cover in the sky during observation (Fig.18b shows the total cloud cover in every month). Generally, the sky is divided into 10 parts. When there is no cloud in the clear sky or less than 0.5 parts are covered, the cloud cover is zero. The cloud covers half of the sky and the cloud cover is 5. Cover the whole sky with clouds and the cloud cover is 10. Calculation steps: 1): divide the cloud layer into high, medium and low families through the radial cloud base height. 2): average each cluster for 30 minutes. 3): Weighted Processing of data in 10 minutes to obtain the integrated cloud cover. Because the calculated cloud cover is a relative value, it does not mean the real cloud cover. Figure 18b shows that the cloud cover is the largest in April. Therefore, the cloud cover in April is set to 1, and the cloud cover in other months is calculated to represent the relative change trend of cloud cover in each month.

'The maximum cloud cover 2.46 in summer' is changed to 'It can be seen from the distribution of cloud cover in every month that there are relatively more cloud cover in summer and the least in winter, indicating that warm atmospheric conditions are more conducive to the formation and development of clouds. '

13. L 394: I suggest adding fig 18c showing the total monthly hours of lidar, radar and simultaneous measurements in this figure. This is essential to understand the reported cloud characterization.

Answer: The total observation hours of MMCR and lidar in each month are shown in Fig. 17. The hours of lidar, MMCR and simultaneous measurements is 872.5 hours. Considering the logic of the manuscript, we decided to put the Figure 17 in L364 in subsection 4.1

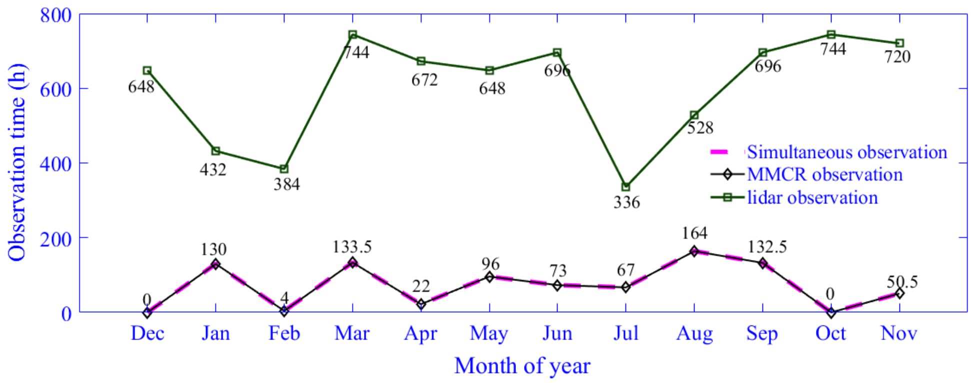

Fig. 17 Monthly observation hours of lidar and MMCR

14. L 396: 'frequency change characteristics…'? This does not make any sense. As the figure caption says it is the frequency distribution of cloud boundaries observed over Xian in 2021.

Answer: L 396: 'Fig. 19 shows the frequency change characteristics of the cloud boundary vertical height distribution in 2021' is changed to 'As the Fig.20 caption says it is the frequency distribution of cloud boundaries observed over Xian from December 2020 to November 2021'.

15. L 424: Remove the word 'statistical'.

Answer: L 424: The word ‘statistical’ has been removed. The modified expression is ‘Based on the analysis of the changes and distribution of cloud boundaries in Xi'an from December 2020 to November 2021.’ At the same time, we have modified and replaced the word ‘statistical’ in other parts to make it closer to the aim of the manuscript. Such as ‘Table 3 Statistical rules of cloud bottom boundary information’ is changed to ‘Table 3 Cloud bottom height recording guideline.’ The word ‘statistical’ in L14 has been removed.