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 responded 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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Major comments:

This manuscript combines lidar and Ka-band millimeter-wave cloud radar (MMCR) to study the cloud macrophysical properties in Xi'an. The authors propose a local method for lidar and MMCR, but without enough details. It would be more interesting if detailed descriptions are added in this manuscript. The statistical analysis is kind of superficial and the English writing needs a full editing. It is difficult to follow for several times. Thus, I recommend a major revision and suggest the authors to rearrange this manuscript carefully.

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. We have added more details to the manuscript to make the logic of the article clearer and the details more perfect. The manuscript has been polished and modified by professional organizations, and I believe that English has been greatly improved. These comments have been revised and supplemented in the manuscript, and the responses to each comment are given below.

1. The title "Lidar and MMCR applied for the study on cloud boundary detection" indicates the manuscript will mainly focus on instruments and method, while the "statistical analysis of cloud distribution in Xi'an region" imply a systematically study for the local cloud distribution. This causes the keynote of the whole text not clear. Which part the authors want to focus, the method or statistical analysis? This would affect the structure of manuscript. Additional, both the method and statistical analysis of the manuscript as current form are not very clear.

Response: According to your requirements and suggestions, a series of modifications have been made in the manuscript. Reorganize the structure of the manuscript, reorganize the highlights and reorganize the language. In order to more clearly express the aim of the manuscript and consider the observation duration of MMCR and lidar, we have 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".

2. The two flow charts of lidar and radar, i.e., Figure 2 and 6, are complex, but the text is too short. I can't tell if they are novel compared with previous methods. If the authors emphasize their method is well-improved, they should carefully introduce this part and show the difference and improvement from others'.

Response: We have modified figures 2 and 6 and added corresponding detailed descriptions as follows.

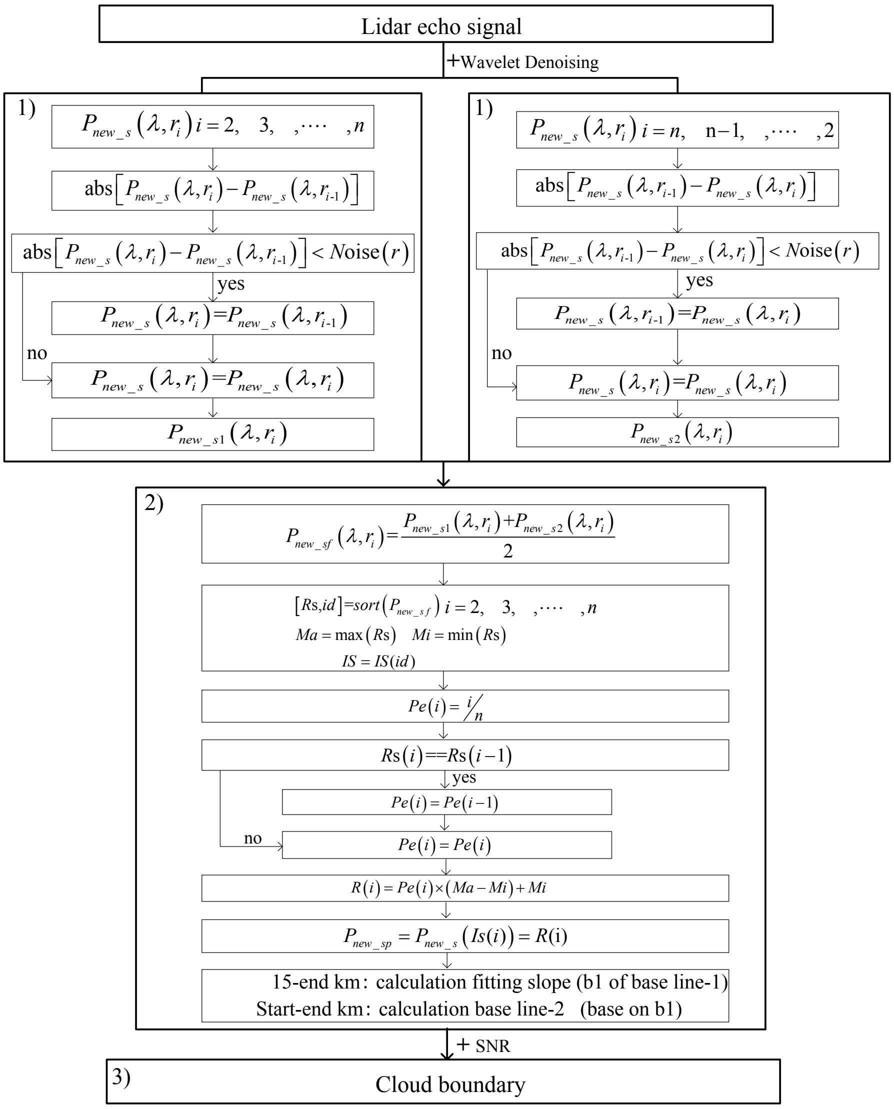

Fig. 2 Use lidar to detect cloud boundary. 1) signal preprocessing, 2) baseline determination based on enhanced signal, 3) identifying cloud boundary with *SNR*

For revised figure 2: After the statistical analysis of the system noise, we set $k = 4$ in this study. The algorithm flow chart of detecting cloud boundary by lidar is shown in Fig. 2. Usually, the moving average of P_{new} (λ,r) of lidar echo signal is calculated to reduce the influence of random noise. However, the selection of a sliding window directly affects the signal quality. Therefore, $P_{new}(\lambda,r)$ is denoised by wavelet transform, threshold function is a soft threshold, wavelet base is sym7, and the number of decomposition layers is 5. Using wavelet function to reduce noise can avoid too much smoothing remove sharp signal changes due to clouds, and can also avoid the improper selection of moving average window. Obtaining cloud boundaries mainly includes three parts. The first part is signal preprocessing. P_{new_s} (λ,r) after wavelet de-noising is discretized based on the estimates of noise, and get useful signals $P_{new\_s1}(\lambda,r)$ and $P_{new\_s2}(\lambda,r)$. The second part is to enhance the signal to make the cloud signal sharper from the background noise and aerosol signal. Average signals P_{new_s1} (λ,r) and $P_{new\_s2}(\lambda,r)$ to obtain $P_{new\_sf}(\lambda,r)$. Ascending arrangement are conducted for $P_{new\_sf}(\lambda,r)$ and the new sequence R_S and the corresponding index *id* are recorded. The maximum and minimum R_S

are denoted as *Ma* and *Mi*, respectively. By building a new mapping proportion coefficient $Pe(i)$, the enhanced signal $P_{new\_sp}(\lambda,r)$ is obtained. Obtain slope of baseline 1, and obtain baseline 2 based on this slope. Signals exceeding baseline 2 are regarded as candidate cloud signals as shown in Fig. 3b) and Fig. 4b). The third part is to extract cloud signal and realize boundary detection by combining the *SNR* of echo signal. By fitting the echo signal slope in the height range of 15–20 km, the slope is used as the bottom slope to distinguish the cloud and aerosol layers (as shown by the magenta line in Fig. 3b and Fig. 4b). Without considering the bottom echo signal (0–2 km), the amplitude of the echo signal received by the lidar decreased with increasing detection height according to the fitted slope, as shown by the blue line baseline in Figs. 3b) and 4b). When the beam senses the presence of clouds, the amplitude of the echo signal will exceed the blue baseline.

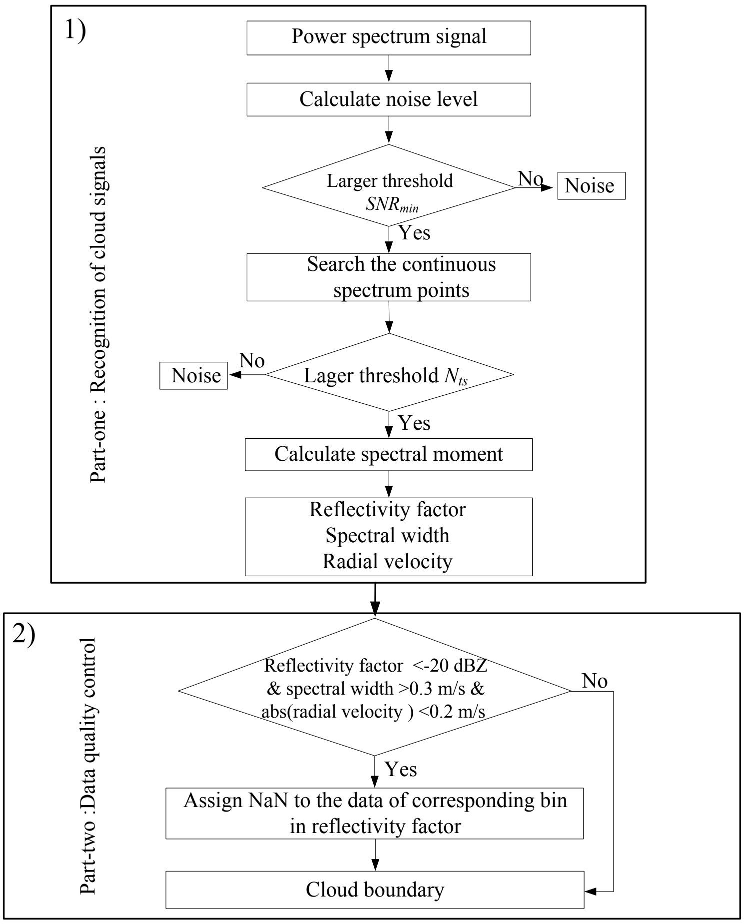

Fig. 6 Flow chart of MMCR cloud boundary detection. 1) recognition of cloud signals from Doppler spectra of MMCR, and 2) cloud boundary with data quality control

For revised figure 6: Identifying cloud signals from Doppler spectra of the MMCR is affected by the noise level, particularly when the *SNR* is low. As shown in Fig. 5, if all spectral points above the noise level are integrated, it will result in a large error in the inversion of its characteristic parameters (reflectivity factor, spectral width, radial velocity, etc.). Therefore, it is necessary to carefully identify cloud signals in Doppler spectra signal. There are two parts in Figure 6 includes two parts:

recognition of cloud signals from Doppler spectra of MMCR and data quality control for MMCR. Part one is mainly to prepare for obtaining effective cloud signals. Generally, cloud signals have a certain number of continuous spectral points and *SNR*. With the part one of Fig.6, We use the segmental method to calculate the noise level, and take it as the noise and signal boundary (as shown is Fig. 5). If spectral data amplitude is greater than SNR_{min}, and search for consecutive velocity bins in its spectral data and record the number of bins. When the number is larger than N_{ts}, and the corresponding spectral signals is determined as an effective spectra segment. Intersections of effective spectral segment and noise and signal boundary are left and right endpoints of cloud spectral, that is, the starting and end point of the spectral moment calculation.

The echo signals of floating debris in the low-level atmosphere have the characteristics of a small reflectivity factor, low velocity, and large spectral width. To further eliminate interfering wave information, we obtained the data quality control threshold by counting the characteristic changes in planktonic echoes in the boundary layer under cloud-free conditions. As shown in 2) of Fig. 6, when the subjective echo intensity Z<-20 dBZ, the absolute value of the radial velocity < 0.2 m/s, and the velocity spectra width >0.3 m/s are used as the threshold for removing non-cloud information; thus the expected data quality control requirements can be met. Cloud boundaries are detected using data quality-controlled cloud echo reflectivity factors.

3. The authors claimed several times "This study will combine the advantages of lidar and MMCR in detecting clouds". While it seems that the results are just simply calculated from the two instruments, respectively. I was hoping some more in-depth combination, like DARDAR for the space-born radar and lidar (Delanoe and Hogan, 2008), whose method is associated with the specific radar/lidar raw observational value.

Response: Dear reviewer, thank you for these valuable references, which we have carefully read and revised the manuscript accordingly based on your suggestions. We have cited these references at the corresponding places in the manuscript. As well as, these references have provided great help for my follow-up research. Obtaining accurate cloud information from echo signals is the premise of in-depth study of cloud micro parameters and analysis of special meteorological variation characteristics. In this study, we propose new methods for cloud boundary detection by lidar and MMC, and combined with special cases to verify and apply those methods. According to this main line of study, the research contents are full.

1). In the manuscript, based on the signal characteristic lidar and MMCR. We propose a new algorithm which suitable for accurately extracting cloud information from lidar echo signals. In order to improve the detection accuracy of MMCR, the cloud signals in Doppler spectra are identified in detail. The appropriate data quality control thresholds are established to effectively eliminate the floating debris echo signal.

2). Using lidar to identify cloud boundaries (cloud bottom and cloud top) is easily affected by aerosol and background noise. We extract the cloud signal effectively by wavelet change noise reduction, signal enhancement combined with the *SNR* of lidar echo signals. This method is not easy to be affected by noise and interfering signals, and also avoids the problem that cloud base and cloud top being overestimated or underestimated due to improper threshold selection. Compared with the previous research literature that directly uses the reflectivity of MMCR for cloud boundary recognition, the manuscript analyzes and calculates the noise level, SNR_{min}, and continuous common points from the initial Doppler spectra data of MMCR. Those make the recognition of meteorological signals more accurate.

3). Based on three special cases, we verified the proposed algorithm, and also clarified the detection advantages of lidar and MMCR under different conditions. Based on three special detection cases, the correctness and reliability of the proposed algorithm are verified, and the detection advantages of lidar and MMCR under different conditions are illustrated.

4). By processing and analyzing the accumulated observation data, a preliminary analysis of the changing characteristics of the cloud boundary is carried out in Xi'an.

So, it is unlikely that more research content needs to be added to the manuscript at present.

4. One-year observation might be too short for statistics analysis of cloud in section 4.2, especially only 302 days of MMCR and 126 days of lidar.

Response: At present, the amount of lidar and MMCR data in the manuscript is not enough to comprehensively and deeply analyze the cloud change distribution characteristics in Xi'an. Therefore, we have replaced or deleted 'statistics' in the text, and re-determined that the purpose of the manuscript is cloud boundary detection method research. The data analysis in the section 4.2 is the application of cloud boundary detection method. It provides a preliminary analysis for the distribution characteristics of cloud boundary in Xi'an. We also point out the contents to be studied in the future.

5. Most of the conclusions (line 413-423) are not new. There are many studies using collocated radar and lidar observation for cloud research, e.g. (Borg et al., 2011) (Dong et al., 2010) (Protat et al., 2011) and so on, which have shown similar results.

Response: L413-423 expresses some well-known advantages and disadvantages of lidar and MMCR for investigation of cloud, which makes the conclusions not detailed and in-depth. Therefore, we re-describe the conclusions (L 404 - 423), and also the points that can be improved in the follow-up of the manuscript are list.

Based on the observation data of lidar, a new algorithm is proposed which can effectively extract cloud signals. Compared with the previous method of identifying cloud bottom and cloud top from echo signals, the new method mainly obtains effective cloud signals through suppressing noise signals and enhancing effective signals to realize cloud boundaries. The algorithm has two main characteristics: 1) in the signal preprocessing, wavelet transform is used for the original signal to avoid the defect of effective information loss caused by improper selection of smooth window; 2) The *SNR* of the signal is considered.

The cloud signals in Doppler spectra are effectively extracted by analyzing the noise level, SNR_{min}, and the continuous spectral points of Doppler spectra. The data quality control conditions for MMCR (reflectivity factor < -20 dBZ, spectra width >0.3 m/s and radial velocity < 0.2 m/s) were established by analyzing the characteristic of the interference of floating debris signals. By analysing the correlation of cloud bottom height between MMCR and lidar, and the cloud bottom height detection by MMCR with data quality control have a good agreement with lidar (the correlation coefficient is 0.803). Therefore, quality control is an important factor to improve signal accuracy of MMCR.

In this study, combined with the respective advantages of MMCR and lidar in cloud detection, the cloud cover and distribution of cloud boundaries characteristics are analyzed based on the observation data in Xi'an from December 2020 to November 2021.The result reveals that more than 34% of the clouds appear in the form of a single layer every month. The cloud cover was lowest in spring and highest in summer. The seasonal variation in cloud boundary height showed that the distribution characteristics of cloud boundaries in spring and summer were similar, and the frequency of high-level clouds in the range of 8–10 km was greater than autumn and winter. The stratiform clouds appearing below 3.5 km in autumn have the highest frequency, and high-level ice clouds or cirrus clouds above 8 km in winter are less likely to appear. The findings can provide a preliminary analysis of cloud boundary changes in Xi'an. If there are huge amounts of simultaneous observation data of lidar and MMCR, the comprehensive statistics and analysis of cloud macro and micro parameters can be realized, which can provide better support for the study of climate change characteristics in Xi'an.

Minor Comments:

1. Line 9, “he” should be “the”

Answer: Write error has been changed to “the”.

2. Line 11, The SNR and SNRmin in the abstract should be explained and given the full description.

Answer: The *SNR* (Signal-to-noise ratio) is the ratio of lidar echo signal to noise signal, dimensionless. The SNR_{min} refers to the noise ratio of the smallest measurable cloud signal in Doppler spectra signal. These have been described in the abstract.

3. Line 14, what does the “rules” mean?

Answer: The “rules” originally expressed the records of observation data in Table 3. We have changed Table 3 to “Cloud bottom height recording guideline”. In L13-15 “Based on the advantages and disadvantages of the two devices in detecting cloud boundaries under different conditions, cloud boundary statistical rules are established to analyze the characteristics of cloud boundary changes in Xi'an in 2021’’ is changed to “Based on the respective advantages of the two devices, the change characteristics of cloud boundary in Xi’an from December 2020 to November 2021 are analyzed with MMCR detection data as the main data and lidar data as assistant data.’’

4. Line 33, what is “high change rate”

Answer: “However, the vertical structure distribution of clouds has great temporal and spatial heterogeneity and a high change rate, which leads to great challenges….” is changed to “However, the vertical structure distribution of clouds has great temporal and spatial heterogeneity, which leads to great challenges….”

5. Line 35-36, remove “direction”, …has always been important for cloud physics.

Answer: “Notwithstanding, research on the characteristics of cloud vertical structures has always been an important direction of cloud physics research. ” is changed to “Notwithstanding, research on the characteristics of cloud vertical structures has always been an important for cloud physics.”

6. Line 50,” dP/dr”, what is P and r, what is “negative to positive”, you mean the value of dP/dr, from negative to positive? Please rephrase this sentence.

Answer: Re-describe L50 as, "Calculation of *dP/dr* using lidar backscattering intensity *P* and range *r*, and the first derivative of backscatter intensity *dP/dr* changes sign from negative to positive and this zero crossing is cloud bottom. "

7. Line 54, what is "detail debugging"

Answer: The 'detail debugging' means that the threshold method needs to be changed according to experience in the calculation process. Unclear expression has been modified in the manuscript.

Line 54, "It is easily affected by noise, and some indicators must be introduced in the specific implementation process to determine the cloud boundary through complex detail debugging, which brings certain difficulties to accurate cloud boundary detection" is changed to "It is easily affected by noise, and restrictive parameters must be introduced in the specific implementation process to determine the cloud boundary by adjusting the parameters, which brings certain difficulties to accurate cloud boundary detection"

8. Line 59, "but the cloud bottom and cloud top detected by this method will be overestimated and underestimated respectively". Does this mean the method would miss some part of cloud, i.e., detect some real cloud signal as noise? This manuscript really needs complete English editing.

Answer: "but the cloud bottom and cloud top detected by this method will be overestimated and underestimated respectively." means that the real signal at the cloud bottom may be considered as noise, and the real signal at the cloud top may be miss. It has been re-expressed as ", but this method takes some real signals at the cloud bottom as noise and miss information at the cloud top, and resulting in overestimation and underestimated of cloud base and cloud top height respectively."
The English language of the manuscript has been polished and modified by professional institutions.

9. Line 65, what is "library". Line 65-67 is different to understand.

Answer: The "distance library" in the line 65 is changed to "gate".
Line 65-67 is re described as: "Kollias et al. (2007) judge step by step from the bottom to the top of the reflectivity. If the *SNR* of 9 consecutive distance gates is greater than the set threshold, these gates represented as cloud signals. Otherwise, they are non-cloud signal."

10. Figure 1. The area could be lager, at least shows some of the "Guanzhong Basin", "Weihe River Basin", "Loess Plateau", "Qinling Mountains" as you described in line 88-90. What does the while line mean? Is it really necessary to show the negative elevation in your color bar?

Answer: The white line in the original diagram originally denotes the Xi'an Region. The revised Fig. 1 contains the "Guanzhong plain", "Weihe River", "Loess Plateau" and "Qinling Mountains" as follow. In the Fig. 1, the black line represents Shaanxi Province, the dark blue represents the Yellow River, and the wathet blue represents the Weihe River.

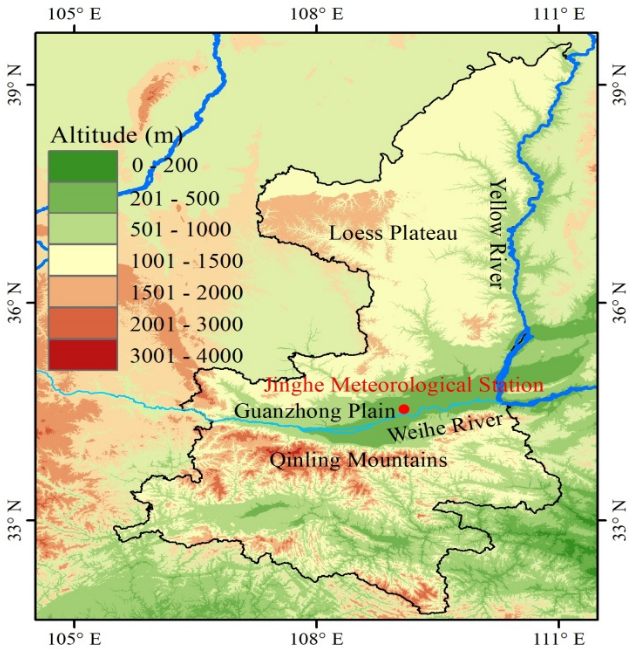

Fig. 1. Geographical coverage of Shaanxi Province (105°29'-111°15'E, 31°42'-39°35'N). The red dot indicates the location of the Jinghe National Meteorological Station in Xi'an.

11. Line 99, what is "HT101"?

Answer: TH101 is the model of the MMCR

12. Line 113-114 is difficult to understand.

Answer: "When using lidar for detection, the laser beam propagates in a clear atmosphere, and the received echo power continuously decreases with increasing detection height. However, the beam into the clouds (or aerosols, etc.), the echo power increases suddenly and becomes stronger at a distance above the cloud bottom. The lidar equation owing to elastic backscattering can be written as (Motty et al., 2018)," was re-described as "The lidar equation owing to elastic backscattering (Motty et al., 2018) can be written as,"

13. Line 116 and line 120, should the N_{bcak} be N_{back}?

Answer: "N_{bcak}" is changed to "N_{back}"

14. Figure 2. "yes" and "no" may be marked in the wrong place. They should be marked after a judgment statement, i.e., ">", "<" or "==", rather than equations. The symbols in the text should be explained. What is "sort", "Pe"? What is the relationship between the three main boxes? It is hard to follow just from line 134-135.

Answer: Sorry, "yes" and "no" are misplaced in the flow chart 2. The revised figure 2 and text description are shown in the Major comments two.

15. Figure 3. The box, axis, tick should be black. The other figures in the manuscript should be changed too. Why the time in title is different with the time in figure? What is the unit of x axis? I notice there are some signal below the blue base line in figure b, especially below cloud base height, around 8 km, 6 km and 4 km. The slope is obviously different with the fitting slope. Does this influence your detection? What is the vertical dashed line in figure c?

Answer: The box, axis, tick of all figures have changed black in the manuscript. The time of the legend in the figure is correct, and "Fig. 3 Detection results of the lidar at 19:15 on March 4, 2021" is wrongly written due to negligence, and has been modified in the paper. The situation in Fig.3b) does not affect the identification of subsequent cloud boundaries, and the signals below the blue baseline (especially at 8 km, 6 km and 4km) are considered as aerosol signals or interference information and will be eliminated. Fig.3c) *S/N* in Shannon formula is the power ratio of signal to noise, which is a dimensionless unit. The blue vertical dotted line is only a schematic auxiliary line in Fig.3c), indicating that the *SNR* of the cloud should be greater than 5 in this case.

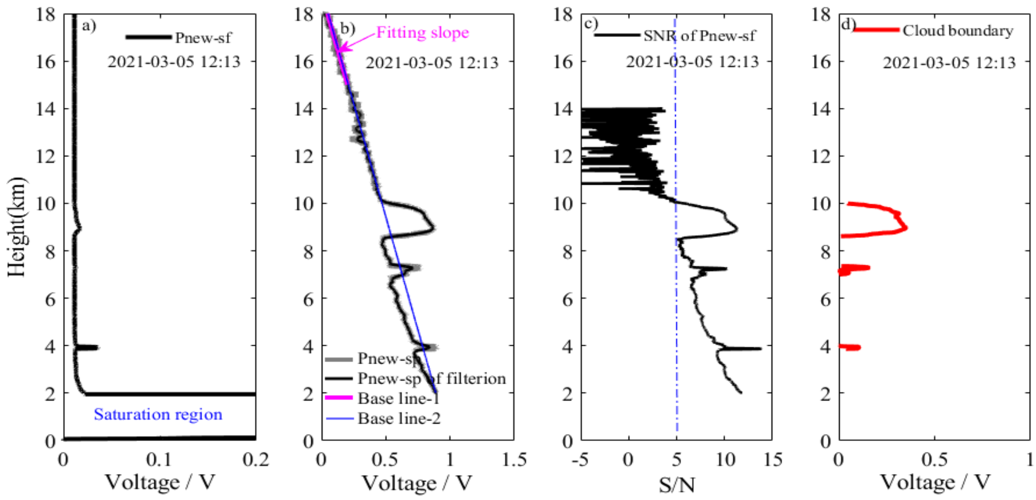

Fig. 3 Detection results of the lidar at 12:13 on March 5, 2021: a) P_{new_sf} of the 1064 nm signal, b) P_{new_sp} of the 1064 nm signal, c) SNR of P_{new_sf}, and d) cloud information detected

16. Figure 6. The "thresh of XXX" should be "Larger/Smaller than thresh of XX". Generally, it should be a judgment statement.

Answer: Figure 6 has been modified. The revised figure 6 and text description are shown in the Major comments two.

17. Line 176, what is N_{ts}?

Answer: N_{ts} represents the threshold value of continuous spectral points. The "N_{ts}" has been described in the manuscript.

18. Line 184-185, please do not use both ">" and "less than" in one sentence. What is the unit of "velocity" and "velocity spectrum width"? And why you choose such thresholds?

Answer: "As shown in Fig. 6b), when the subjective echo intensity Z<-20 dBZ, the absolute value of radial velocity is less than 0.2, and the velocity spectrum width >0.3 is used as the threshold for removing nonmeteorological information, the expected data quality control requirements can be met." is changed to "As shown in Fig. 6b), when reflectivity Z<-20 dBZ, the absolute value of radial velocity < 0.2 m/s, and the velocity spectra width >0.3 m/s are used as the threshold for removing non-cloud information, the expected data quality control requirements can be met.''

19. Figure 7. Is the unit of velocity spectrum width in figure c "m/s"? Figure a, echo emissivity factor is the same as "reflectivity factor"?

Answer: Yes, the unit of velocity spectra width is m/s in Figs7. c). "Figure7 a), echo emissivity factor" and "reflectivity factor" in Figs 7. a) and d) are consistent, and they are uniformly expressed as 'reflectivity' in the manuscript.

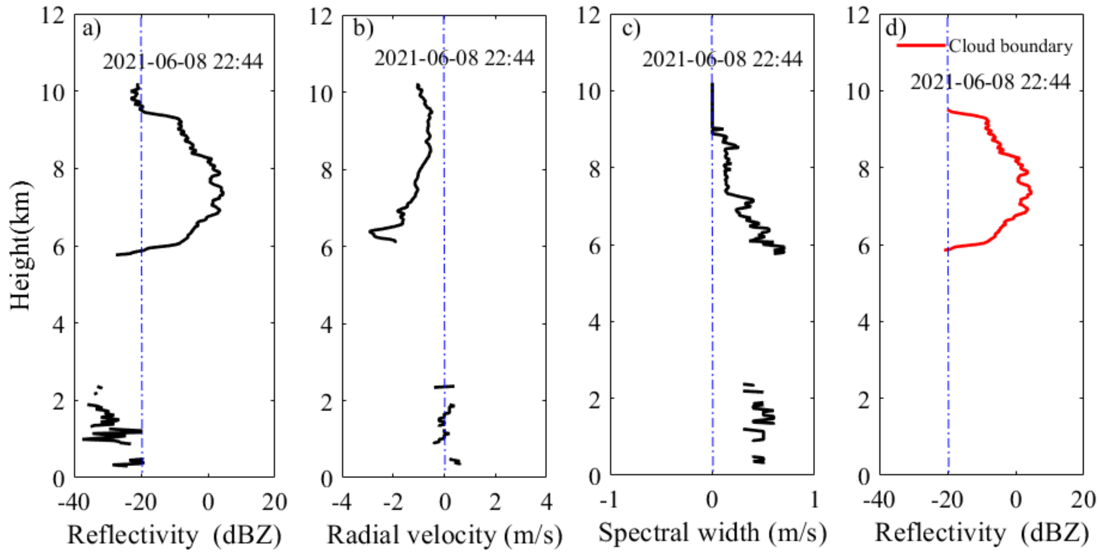

Fig. 7 Meteorological signals of MMCR at 22:44 on June 8, 2021. a) reflectivity, b) radial velocity, c) velocity spectra width, d) echo emissivity factor after quality control

20. Line 212, What is "time-height-indicator information"? Do you mean "vertical profile"?

Answer: No, "time height indicator information" is used to describe the long-term observation results in Fig. 8." The sentence is re-described in the manuscript.

"According to the data method described in Section 3.1, the SNR of P_{new_sf} and P_{new_sp} of the echo signal of the lidar @1064 nm are obtained time-height-indicator information (THI) and are shown in Figs. 8a) and 8b)." is changed to "According to the data method described in Section 3.1, we can obtain cloud change information of time-height-indicator (THI) for *SNR* of P_{new_sf} and P_{new_sp} of lidar @1064nm with a duration of 7 hours, as shown in Figs. 8a) and 8b)."

21. Line 214-215, "After 05:00, the cloud layer developed deeper". Does this infer from Figure 9, the MMCR observation? It would be clearer if you combine Figure 8, 9 and 10 together to see the difference of the two instruments. Same as Fig 11-13, and Fig 14, 15.

Answer: Yes, this phenomenon can be seen from Figure 9 that the clouds are developing deeply. We have combined figure 8 and Figure 9 in the original text and described them again. It can be seen from Fig.8 d) that the cloud layer developed deeper after 5:00, and the laser beam penetrated 0.1 km into the cloud layer and was quickly attenuated.

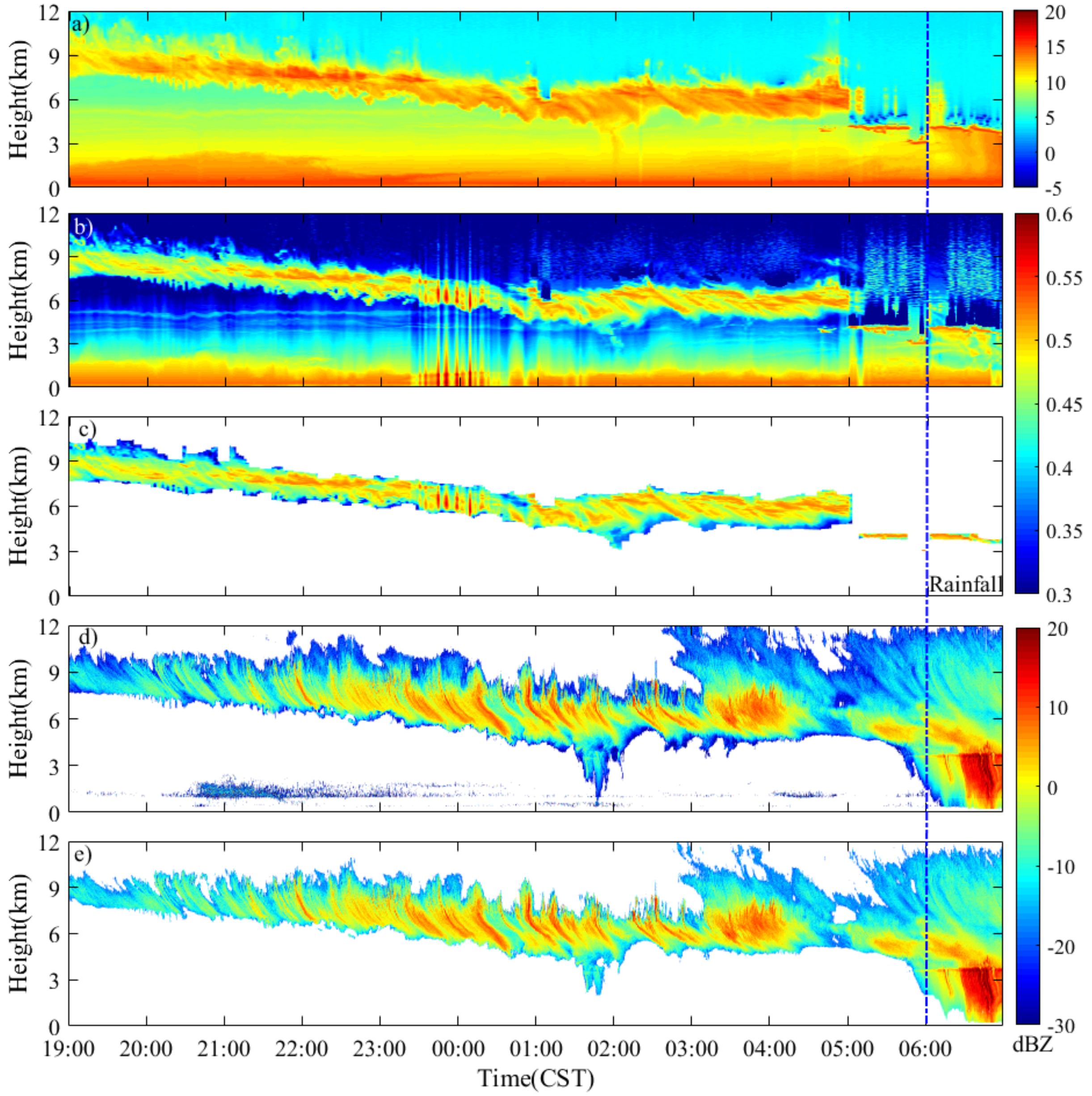

Fig. 8 The THI of echo signal of the lidar and MMCR on March 4 to 5, 2021. a) *SNR* of the 1064 nm signal, b) P_{new_sp} of the 1064 nm signal, c) cloud information detection results of the lidar, d) reflectivity of the MMCR without quality control, e) reflectivity the MMCR with quality control (dotted line indicates rainfall time)

22. Line 216, "Rainfall begins at 06:00", how do you get the time of rainfall, do you have rain gauge or other observations? Please explain this in Section 2.

Answer: We checked the time of rainfall recorded by microwave radiometer, which is close to MMCR. The record of rainfall time has been described in the manuscript.

23. Figure 8. What is the stripe in figure b around 23:00-01:00? Does this affect your detection results? What does the "SNR>5.2" in figure c stand for?

Answer: The stripes around 23:00-01:00 in Fig. 8b are caused by the instability of the laser seed, which causes slight fluctuations in the emitted light energy, but this does not affect lidar detection of clouds, nor does it affect the recognition of cloud boundary. "SNR >5.2" in Fig.8 c) indicates that we get the cloud boundary shown in Fig. 8c), we only retain the effective data lattice with SNR >5.2 (regardless of the underlying signal saturation region) in Fig. 8a).

25. Line 232, "the cloud layer starts at 03:00", does this mean the signal before 03:00 is not cloud?

Answer: No. The information displayed is cloud signal from 19:00 to 06:00 in Fig.9b). "From the THI of the echo reflectivity of the cloud, the cloud layer starts at 03:00 and gradually develops from 7 km to 12 km (the lidar signal fails to show this detail)." is changed to "According to the echo emissivity factor of the MMCR, from 03:00 to the end of observation, the cloud layer developed deeper, the cloud bottom height gradually decreased from 7 km to 300m, and the cloud top height developed to ~12 km (the lidar signal fails to show this detail). "

26. Line 253-254, "From the characteristic distribution of the P_{new_sp} signal in Fig. 11b), the low-level cloud rained from 18:30 to 18:45", how does this be concluded, just by the sudden decree of cloud base?

Answer: In the observation experiment at 18:30 on March 4, 2021, we felt that there were small showers on the ground and the duration was ~10 mins. Then we checked the rainfall time recorded by microwave radiometer (recording every 2 min), and the specific rainfall period was 18:30~18:45 CST and the precipitation reached the ground. At the same time, the radial velocity of MMCR showed that the velocity reaches ~-4m/s in this period.

27. Line 273, "During the period from 15:00 to 01:00", where is "15:00" in figure 12?

Answer: Sorry, I mistakenly wrote 17:00 as 15:00 due to negligence. "During the period from 15:00 to 01:00…" is changed to "During the period from 17:00 to 01:00…"

28. Figure 13, Could you please at least use one specific color/line style/marker to represent one property (cloud base or top/first or second layer/lidar or MMCR)?

Answer: The changed Figure 13 as below.

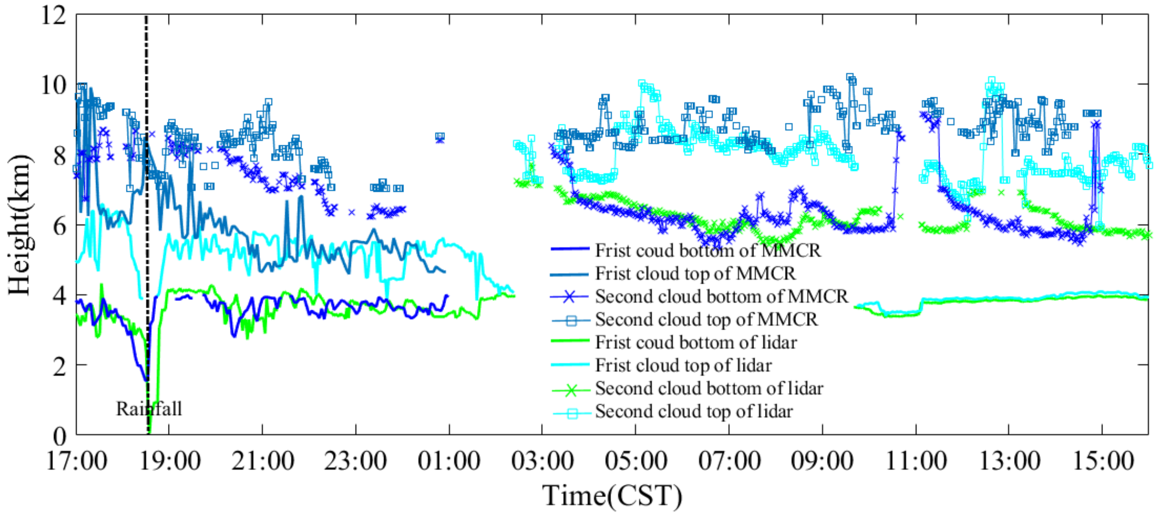

Fig. 13 Cloud boundary detected by the lidar and MMCR from March 4 to 5, 2021

29. Line 294, "Case three studies of precipitating cloud", the figures of case one and two are also have been marked with rainfall. If you want to discuss precipitating cloud separately, the case one and two should be non-precipitating cloud.

Answer: We changed the objectives of the three study cases to the following,

"1) Case one studies of double-layer clouds" is changed to "1) First case study period".

"2) Case two studies of double-layer clouds" is changed to "2) Second case study period".

"3) Case three studies of precipitating cloud" is changed to "3) Third case study period".

30. Line 310, what is "rain storage"?

Answer: The "rain storage" means "rain virga". "As the observation time progresses, the phenomenon of rain storage (reflectivity >-15 dBZ) occurs in the cloud" is changed to "As the observation time progresses, the phenomenon of rain virga (reflectivity >-15 dBZ) occurs in the cloud"

31. Figure 15. How the cloud base height being determined for precipitating cloud, such as after 11:00? I don't think the cloud base height around 0 km is appropriate. This may explain why the cloud base height in figure 19 has a such huge peak at lower level.

Answer: When rainfall is slightly more intense, neither laser radar nor millimeter radar achieves an accurate assessment of cloud base height (visiting a balloon perhaps achieves an approximate detection but is not part of this paper's research content). Figure11: the cloud base height after 11:00 is 0.27 km instead of 0 m. In the Fig. 15, because there are a larger number of plotted points, the cloud bottom height around 0 km is appropriate.

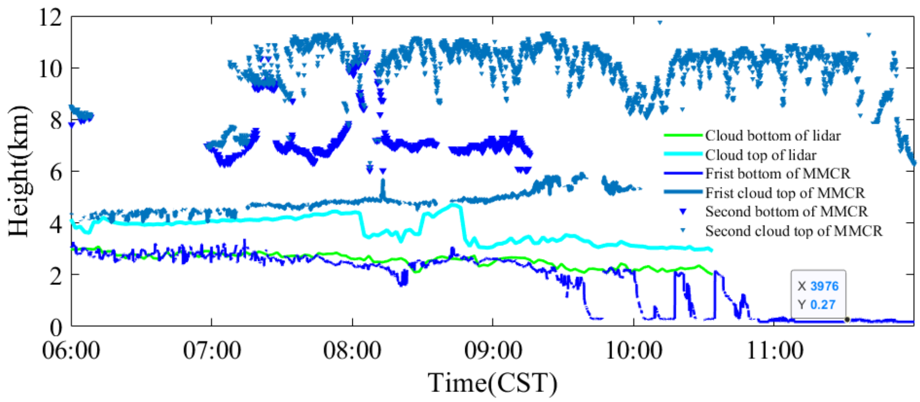

Fig. 15 Cloud boundary detected by the lidar and MMCR on March 10, 2021

32. Line 338, the 126 days of lidar observations seems too short for one year. Can the authors explain why is that? Is there any issue of the lidar, if so, does this issue affect the observed results?

Answer: The main task of the lidar in the manuscript is to monitor special weather changes, so the data volume is only 126 days in 2021. This does not affect our cloud boundary analysis for the whole year, because MMCR data are mainly used in cloud boundary analysis.

33. Line 341-342, "we plan to employ MMCR data to replace the data of periods when the lidar is not running" What do you mean by "replace"? You mean the MMCR data are only useful when lidar is not running? Generally, I am not sure the purpose of Figure 16 and Table 3. "bottom of MMCR is blurred" in Table 3, what does this mean? Are the results of table 3 accomplished by manual selection?

Answer: According to the results discussed in the previous chapters, lidar has more advantages than MMCR in cloud bottom detection. Therefore, lidar (detecting cloud bottom) and MMCR (detecting cloud top) can be combined to detect cloud boundary (cloud bottom and cloud top), but considering the continuous observation time of lidar, it is not enough to analyze the change of cloud bottom all the year. Therefore, we analyzed the correlation between the cloud bottom detected by MMCR with quality control and lidar, and the correlation coefficient is 0.803. Therefore, the cloud bottom height during the period when the lidar is not running is provided by MMCR to realize the annual cloud boundary change in Xi'an.

Figure 16 mainly shows that the cloud bottom height is good agreement with the lidar and MMCR with data quality control. Therefore, when the lidar is not operational, the cloud bottom information can be provided by MMCR.

The "bottom of MMCR is blurred" in Table 3 indicates that the MMCR cannot accurately identify the cloud bottom in light rain or drizzle. "Bottom of MMCR is blurred" is changed to "bottom of MMCR is invalid".

The data selection in Table 3 is provided by our developed algorithm.

34. Line 379, “20217” should be “2017”.

Answer: Sorry, “20217” has been changed to “2017”.

35. Line 385-386, “The months with the largest (96%) and smallest (42%) cloud occurrence frequencies are August and December, respectively.” Does this mean the Jinghe National Meteorological Station are nearly covered by cloud during the whole month of August? Does it make any sense?

Answer: “The months with the largest (96%) and smallest (42%) cloud occurrence frequencies are August and December, respectively.” indicates that 96% and 42% of all profiles detected in the 22 days of August and 30 days of December contain cloud profiles, indicating that the frequency of cloud formation is the highest and lowest in August and December respectively. This number of ‘96%’ is relatively large, and Line l389 explains why “96%” is large.

36. Line 390-391 and figure 18b, how the “normalized monthly distribution” be calculated? “the minimum cloud amount is 0.65 in spring and the maximum is 2.46 in summer”, how do these two numbers be inferred?

Answer: 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 minimum cloud amount is 0.65 in spring and the maximum is 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.

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The above content is a detailed reply to your comments and suggestions. Thank you again for your valuable and valuable comments. Finally, I hope you can recommend my manuscript to Atmospheric Measurement Techniques. Thank you very much!