Response to reviewer #1

General Comments:

This study presents an observation method for detecting atmospheric column condensates by combining millimeter-wave radar (MWR), lidar and microwave radiometers. This work is interesting and meaningful. Especially, the authors stated that it is the first application to operate observations of atmospheric column condensates. However, there are some issues in this manuscript, as listed below, that need to be carefully considered. Moreover, the English should be improved substantially, especially for Abstract and Results and discussions. I think this manuscript can be considered for publication only if the author could adequately address the comments below.

Response: We appreciate the reviewer's thoughtful review and constructive comments. All the comments have been addressed in the revised manuscript, and the responses to each comment are given below. The manuscript has been polished and revised by professional institutions, and I believe that the English has been improved greatly.

Specific comments:

1. Lines 16-18. The author specifically mentions stratiform clouds. Is their atmospheric columnar condensate calculated differently? Moreover, the atmospheric column condensate in stratiform clouds is calculated by the saturated water vapor density and vertical airflow velocity, but the saturated water vapor density is not mentioned in the later observed quantities in the abstract.

Answer: The main feature of stratiform cloud is that it has a large coverage and is relatively unified on the horizontal scale. The measurement results of one point can be used to represent the situation of a large area. However, the detection method provided in this paper is suitable for all types of clouds, not only for stratiform clouds, but also for convective clouds, and etc. This paper mainly provides a method for measuring air condensate. In order to avoid ambiguity, the "stratiform clouds" in Line 16 is deleted in the revised draft. The saturated water vapor density cannot be directly measured by remote sensing equipment. It can be derived by the temperature. The description is also added in line 20-21. The discussion about different types of clouds can be found in the last part (Line 364 to 379).

2. The authors keep emphasizing that it is "atmospheric column condensate", but the actual object of observation is cloud, so would it be more appropriate to change it to "cloud column condensate"?

Answer: The reviewer's suggestion is very meaningful. The actual object of observation is cloud, so Cloud column condensate should be correct and can be used. But we think "atmospheric column condensate" in this paper is more appropriate. From the perspective of metrology, the results expressed by atmospheric column condensate and cloud condensate are consistent. However, from the perspective of cloud water resources assessment, what we need to know is the condensate that may be generated in an atmospheric column. Of course, this condensate is mainly measured after cloud formation. Atmospheric column condensate can better express this meaning.

3. Figure 1. The authors should provide appropriate explanations for the schematic diagram. g., it is not clear whether the horizontal arrows of "Input or output airflow" represent total input or output, or just the horizontally oriented input or output.

Answer: The reviewers are rigorous. The appropriate explanations for the schematic diagram of Fig.1 have been added in Line 74-76.

4. Lines 116-117. To my knowledge, the unit of saturated water vapor density is g/m^3. Please check it.

Answer: Sorry, I made a clerical mistake. The reviewer was right. the unit of saturated water vapor density is g/m^3. It has been revised in the text in Line 124.

5. Lines 123-125. Please define R_v and give a reference to the equation's source. Furthermore, e is the water vapor pressure, and its unit should be similar to hPa, not kg/m^3. Please check it.

Answer: Sorry, I made a clerical mistake. The reviewer was right. The water vapor pressure's unit, not kg/m^3. It has been revised in the text in Line 131.

6. Figure 2. P_{cong} means the net flux from t1 to t2, so the label "Columnar condensation water" in the figure seems inappropriate.

Answer: Columnar condensation water is obtained by integrating the net water vapor flux from t_1 to t_2. A step is missing in the original figure and has been added.

7. Lines 182-183. Does the overline mean sum or average? What's more, the formula is valid on the assumption that the detection errors of S and V do not vary with time and are independent of each other. This should be declared in advance.

Answer: The overline mean the average of parameters in a short measurement period, which has been added in Line 193. Formulas 9 and 10 are valid on the assumption that the detection errors of S and V do not vary with time and are independent of each other. This has been declared in Line 189-190.

8. Figure 6. It seems difficult for the reader to understand in detail how the vertical velocity is obtained from the schematic. Additional instructions need to be provided.

Answer: Assuming that the vertical motion of the atmosphere is uniform during MWR detection, the Doppler velocity from small to large corresponds to the particle size from small to large. The size distribution of supercooled liquid droplet is relatively narrow, their spectrum can be closely approximated by a Gaussian model. Then the first spectral point on the left side of the power spectrum represents the signal of the smallest particle that can be detected by the radar. If the particle is small enough, it can be used to derive vertical air motion. The specific schematic diagram has been added in the text.

The sizes of typical supercooled liquid droplets range from 5 to 20 μm. The terminal velocities are in the order of 0.03 m s^{-1} and 0.07 m s^{-1} for 10-μm and 50-μm liquid droplets, respectively. Given their negligible fall velocities, these cloud droplets can be used as tracers for air motions. In Doppler radar spectra the radar returns from liquid cloud droplets can be identified as a narrow peak around 0 m s^{-1}. The mean velocity of this peak can be used to derive vertical air motion. As the size distribution of supercooled liquid droplet is relatively narrow, their spectrum can be closely approximated by a Gaussian model.

9. Lines 255-260. Reflections from raindrops can interfere with the signal, so how much uncertainty is there in wind speed measurements in rainy conditions?

Answer: In case of heavy rainfall, the particle reflection does not belong to the Rayleigh scattering area, and the detection results may not be true and reliable. In case of drizzle, the power spectra of drizzle and cloud droplets will partially overlap. At this time, the wind speed can not be solved directly by the little particle tracer air motions method, and the power spectra of the two need to be further decomposed. Some literature (Frisch, A. S et al., 1995) studies show that the existence of drizzle will affect the cloud difference by nearly 36%.

Frisch, A. S. , C. W. Fairall , and J. B. Snider . "Measurement of Stratus Cloud and Drizzle Parameters in ASTEX with a K α -Band Doppler Radar and a Microwave Radiometer." Journal of the Atmospheric Sciences 52.16(1995):2788-2799.

10. Lines 287-289. A result picture of the cloud phase state should be shown.

Answer: See the answer 11 below.

11. Lines 295-297. The results of the microwave radiometer should be displayed and validated in Sect. 6. Moreover, how was the final temperature determined in figure 10? Is it a combination of rotational Raman lidar and microwave radiometer measurements?

Answer: Yes, Figure 10 shows the combination of rotational Raman lidar and microwave radiometer measurements. This has been declared in Line 300 to 305.

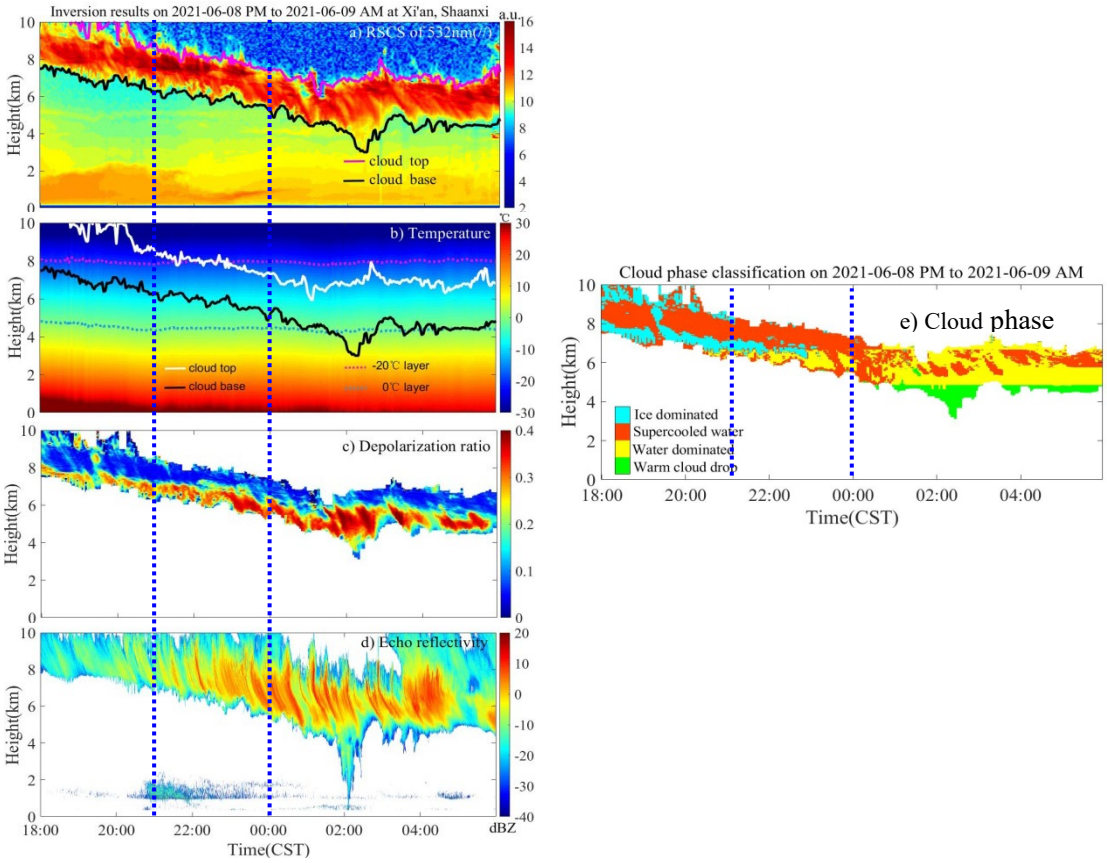

Figure 1 Cloud phase classification using multi-source ground-based remote sensing data

Answer: For questions 10 and 11: for this layer of precipitating cloud, we used multi-source ground-based remote sensing data to analyze the cloud phase in detail based on clustering algorithm, the results are shown in figure 1. Figure 1 (b) shows the temperature measurement results during the observation process by using rotating Raman lidar and microwave radiometer, and figure1 (e) shows the cloud phase recognition results. Supercooled water and water are dominant in the cloud layer from 21:00 to 23:59, but water is mainly distributed at the cloud base and top. Therefore, it can be used for the movement speed of the particle and characterize the vertical movement speed of the atmosphere.

12. Figure 12. The y-axis label "Condensation water" seems inappropriate, since it is the water vapor flux. And why are there only positive flux values in the figure?

Answer: The reviewer was correct, the y-axis label "Condensation water"is inappropriate, is has been corrected as "water vapor flux". Water vapor flux should have positive and negative values. The water vapor flux entering the cloud is recorded as positive, and the water vapor flux leaving the cloud is marked as negative. Only the water vapor entering the cloud may become condensate. Figure 12 only shows the water vapor flux into the cloud.

13. Lines 326-329. (1) The authors say that "the condensate in the period from 21:00 to 23:00 was integrated" and that "rainfall at 06:00 a.m.", but what about the water vapor input and output from 23:00 to 6:00. It should be clarified. (2) According to the description, the total amount of the

maximum possible condensate counted in this manuscript was 88.2 g (2.94 mm). The atmospheric column condensate can be obtained by integrating the instantaneous water vapor flux. It is worth noting that the unit of instantaneous water vapor flux is $g/m^2/s$, and its unit after integration with respect to time (s) should be g/m^2. This indicates in a physical sense how many grams of water vapor is transmitted per square meter (input or output). So I don't understand how the authors got the results in g or even mm.

Answer: During the period of 21:00-23:59 (it is marked with blue dotted line in Fig. 8), the temperature and vertical velocity of the cloud boundary were detected, and the saturated water vapor density of the cloud boundary was calculated according to the temperature. The water vapor flux into the cloud during this period, that is, the maximum possible condensate, was deduced. From figures 7 and 8, the cloud bottom height keeps falling, indicating that water vapor is constantly replenished into the clouds and condensed water was generated. The column condensate after 23:59 is not calculated in this paper, mainly because the vertical velocity calculated by the minimum particle tracing method of millimeter wave radar is inaccurate, which will introduce large calculation deviation. These descriptions have been added to the Line 305-310 of the text

Thank the reviewers for their preciseness and seriousness, water vapor flux's unit after integration with respect to time (s) should be g/m^2. This error has been corrected and revised in the text. "mm" is the unit used to describe the amount of rainfall in meteorology, what does it mean is "mm/m^2".

Minor comments:

1. Line 36 and Line 65. The abbreviations need to be defined in the abstract and then again at the first instance in the rest of the text.

Answer: The full name of the abbreviation (CWR and MWR) has been added in Line 36 and Line 65.

2. Line 78. The right side seems to be GMh. This is not accurate.

Answer: "The right side" has been changed as "the middle".

3. Line 162. The abbreviation RH is not needed because it is not used later. The same situation in photomultiplier tubes (PMTs), pure rotational Raman (PRR) and so on.

Answer: These unused abbreviations have been deleted in the revision.

4. Line 252. The W_{air} needs to be defined at the first appearance.

Answer: The error has been corrected.

5. Lines 269-270. The caption should be improved.

Answer: The error has been corrected.

6. Line 277. The name should not be all caps, also in Line 304.

Answer: The error has been corrected.

7. Figure 10. In the title of the picture, "… cloud topon …" should be "… cloud top on …". And drawing a 0-value line in the picture can better help the reader capture the information.

Answer: The error has been corrected.