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We appreciate Håkansson for her valuable comments and instructions, which helped us to improve the description of results and expressions of the manuscript. Below are the responses to her comments. Modifications in the text are marked with different color. Revised figures, including Figs.2/4/5/7/8/9/10 are pointed out in our responses.

1 General comments

The paper compares cloud top height retrievals from two different algorithms on different sensors (MODIS and AHI) with ground based radar data over Beijing. Retrieval accuracy was found to be comparable for the two imagers/algorithms and better for thicker clouds. Results where presented in terms of bias, standard deviation and the percentage of retrieval errors within 0.25, 0.5 and 1km. Overall the paper is well organized and clear but some claims are not supported by the results and references to previous validations of MODIS collection 6 using radar data is missing. Special comment about a missing reference: I am the first author of paper Neural network cloud top pressure and height for MODIS Håkansson et al. 2018: https://www.atmos-meas-tech.net/11/3177/2018/amt-11-3177- 2018-metrics.html. This is a recent paper (2018) evaluating MODIS collection 6 like this paper (not MODIS collection 5 as most of the currently referenced papers) using global space borne CloudSat (CPR) radar data. The results are comparable to the ones in this paper. Further it does discuss which statistical measures are appropriate for describing the resulting non-Gaussian CTH error distributions. I apologize in advance for bringing up my own research but I believe it is very relevant in this case and that this is an important reference that should be included in the article. I am sure the editor or other reviewers can help you decide on inclusion or not, as I am biased.

We are very sorry for missing the reference of Håkansson et al. 2018. Their study is relevant and should be included.

Håkansson et al. (2018) discussed which statistical method was suitable for illustrating the cloud top height difference. Their analysis results presented the instructions how to analyze and show the comparison differences in a more accurate and complete way. According to reviewer's suggestions, we add the analysis of median and IQR differences. Relevant figures and statements are also modified.

2 Specific comments

1. Line 12: *"Large differences were mainly occurring for the retrieval of thin clouds of CD < 1 km, especially clouds higher than 4 km"*. seem to be in contradiction to the results at line 13-14: *"MODIS CTHs greater than 6 km showed better agreement with the radar data than those less than 4 km"*. High clouds can not both have better agreement and larger differences? It would be clearer if you add a sentence detailing that radar high thin clouds with large differences will typically have low MODIS CTHs.

   The "CD" and the cloud base height are derived from radar measurement. Only MODIS CTHs are retrieved from MODIS. "High cloud" means cloud has high "radar" base height, but not high MODIS CTH. There are some high and thin "radar" clouds that have low MODIS CTHs. Just as reviewer had mentioned in the comments 20, "the thin high clouds had a high chance of ending up as MOIDS low clouds".

   To avoid the confusion and make the expression clearer, *"Large differences were mainly occurring for the retrieval of thin clouds of CD < 1 km, especially clouds higher than 4 km" is*

revised as "Large differences were mainly occurring on the retrieval of thin clouds of CD < 1 km, especially when the cloud base height is higher than 4 km". The sentence "*MODIS CTHs greater than 6 km showed better agreement with the radar data than those less than 4 km*" is revised as: "*It was found that MODIS CTHs with higher value (i.e. > 6 km) showed smaller difference to radar CTH than those MODIS CTHs with lower value (i.e. < 4km).* "

2. Line 23: *"Statistical analysis showed that the average AHI CTHs were lower than the average MODIS CTHs by −0.64 ± 2.36 km."* For me it was not immediately clear that AHI CTH is statistically significant lower than MODIS CTH given the error distribution. As we are only looking at a sample and the true distribution might very well be centered at zero (as the SD is large and bias is small). Inclusion of a one sample two sided t-test showing that the true bias is not equal to zero would give more support to the claim. However assuming a sample size of 600 the result seem to be significant.

   To inspect what reviewer doubted, we added the probability density of the CTH difference between AHI and MODIS in Fig.9. The CTH differences are given in an added Table 3. The peak CTH difference is -0.18 km and the median is -0.43. It is related with the non-Gaussian distribution of difference what reviewer had discussed in her paper.

3. As seen in figure 4-b the error distributions are non-Gaussian. This makes the interpretation of bias/STD difficult for the reader (see Håkansson et al. 2018 for a longer discussion). Inclusion of medians (or modes) and mean absolute error (or interquartile range) would be helpful. At least medians should be included and discussed.

   We agree with reviewer's suggestions. Only mean (STD) value is inadequate to describe whole CTH difference. We add the median and IQR of all CHT differences analysis which helps readers to get the distribution of difference. Figure 4 and relevant expressions are revised.

4. Line 29: change "is" to "can be" or reformulate to make it clear that the assumption that *"cloud is regarded as black bodies"* is not made by all algorithms. And at least it is not made for all cloud types. Clouds regarded as black bodies are also regarded as opaque. And many algorithms handle also semi-transparent cloud with some skill.

   Sorry for our inaccurate expression. It is revised as "that an opaque cloud can be regarded as a black body".

5. Line 30: Remove the word *"Surface"*. I agree that active sensors are ideal for accurately detection of CTH. Space borne active sensors have the benefit of global coverage. What is the benefit of ground based ones? Is there smaller problem with clutter for ground based radars compared to space borne radars?

   Yes. We agree with reviewer. The "surface" word has been removed.

6. Line 38-39: Many references to MODIS collection 5. Baum et al. is the only one using MODIS collection 6 data and it uses space borne lidar (not radar) for validation. I suggest updating the references list, and at least add more studies of MODIS collection 6 validated with radar data.

   Sorry for our incomplete research investigations of the background. According to reviewer's suggestion, we have made more careful investigations about recent and previous studies and some references are added in the manuscript.

7. Line 40-44: It is better to include validation results for MODIS collection 6 as that is what you are using. And especially as Baum et al. 2012 shows that CTH is much improved in Collection 6 compared to Collection 5.

   According to reviewer's comment, the comparison work for MODIS collection 6 is included in the manuscript.

8. Reformulate/ or remove *"Evaluation results from previous studies are not representative of specific regions".* The results in global investigations might or might not differ from specific regions, it can not be assumed to be different. It might be different though and that is one reason why your investigation is important.

   It is revised as "Previous global evaluation results might be different to the specific regions".

9. Line 70: A remark: Note that as the CO2 slicing is used only for mid- and high- level clouds, height estimation is needed before the height retrieval can start. A bit of a hen and egg problem.

   It might be better to say that "the CO_2 slicing is appropriate only for mid- and high- level clouds". In CO_2 slicing technology, the emissivity of the cloud is assumed to be the same at both wavelengths. The assumption is nearly correct for ice clouds and introduces a very small error, but less so for water clouds. We delete this sentence to remove the confusion, add another statement at the end of this paragraph.

10. Line 80: *"Most published evaluation studies on the MODIS cloud top properties are from the Collection-5 version datasets"*. Include and relate your results to some more studies using MODIS Collection 6 CTH data.

    According to reviewer's suggestion, we reformulate the expression. As the purpose of this section is to present a brief description of the MODIS CTH retrieval algorithm, the relevant studies recently published are added in the Introduction.

11. What is the intercept method and what is the interpolation method? Please describe them.

    We add the description of two methods in the manuscript according to reviewer's advice.

12. What method/algorithm/product is used to determine which clouds are semi- transparent?

    The AHI cloud type product indicates the cloud type, which is then used to determine the retrieval method. We have added expressions in the manuscript.

13. Line 107: Are any such *"short-term collaborative observations"* affecting the data used in the study.

    NO. Only vertically pointed Ka-band radar data were used for comparisons. Data from short-term collaborative observations were not included in this study.

14. Line 115: Did you use a lower threshold to include more clouds with weak returns? Or would a lower threshold include more clouds with weak returns that you do not wish to include? Is there a risk for non clouds contamination the results, like aerosols or insects? Please clarify.

    Sorry for our incorrect writing. It should be "*A higher threshold might miss some clouds with weak returns.*"

    The threshold, to some extent, implies the detection ability of radar. Lower threshold indicates stronger detection ability. Our radar can measure very weak returns, like -45 dBz because it uses a magnetron transmitter. A Ka-band radar, equipped with all-solid transmitter,

generally cannot measure weak returns lower than -40 dBz.

There is no risk using lower threshold since the insects generally have strong returns. Aerosols exert main impacts on the visible band but not the Ka band. It is not associated with the weak returns.

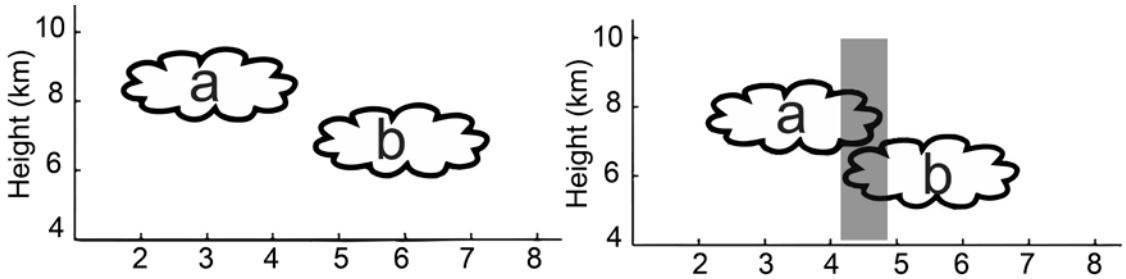
Attenuations due to water vapor, oxygen, cloud and precipitation will weaken the returns, and then may underestimate the cloud top height. Thus, if radar transmits weak signal, it is likely to miss some clouds with weaker returns.

15. Table 1. That is a high vertical resolution of 30m! Does this mean that the thinnest clouds detected (three cloudy bins) are only 90m thick? What is the horizontal resolution of the radar data? Please include it in the table.

    Yes. Three cloudy bins are 90m. The horizontal resolution of radar data is flexible. It is related with the radar pulse width, pulse repetition frequency, the moving speed of the target, etc. The "Pulse repetition frequency" is added in the table 1. More details about the horizontal resolution are given in our responses to the comment 20.

16. Line127-130: *"For comparison with satellite data, for multilayer clouds in a period, the CTH is also the average CTH of all cloudy profiles even if the upper-level clouds do not cover the lower-level cloud, rather than the average CTH of the upper-level clouds."* This sentence is confusing. Is at any point the CTH of the second level of a multi-layer radar profile included in the averaging? I think the first part of the definition of the radar CTH is very clear as it is. Can the second part be reformulated more like: *Note that for multilayer clouds only the CTH of the highest cloud is used. In the case of a cloudy period/scan with a low cloud which is partly covered by a high second layer cloud the resulting CTH will be an average of the CTH of the upper layer (from the parts with multilayer clouds) and the CTH of the lower layer (from the single-layer parts of the period/scan)*. Or include a figure to make it clear what is done.

    Sorry for our poor writing. The cloud top height is not the top height of upper-level cloud. A figure below helps to understand the meaning. In the left figure, final radar CTH is the average CTH of all cloudy profiles of cloud 'a' and cloud 'b' because two clouds are separated. In the right figure, final radar CTH is the average CTH of all cloudy profiles of cloud 'a' and part cloudy profiles of cloud 'b' (cloudy profiles in the gray frame are not included). Note that radar CTH is not the mean CTH of cloud 'a' at the upper level.



    These sentence are revised as "In order to compare with satellite data, for clouds detected in a period (i.e. within 5 min or 15 min), the radar CTH is calculated as the mean CTH of all cloudy profiles but not the mean CTH of upper-level cloud if there are multi-layer clouds. That is, the radar CTH might be different to the CTH of upper-level cloud if the upper-level cloud does not cover low-level cloud completely. "

17. Line 133: Suggestion: replace *"data covers larger areas"* to *"have larger field of views*".

    "Field of view" may be inappropriate here because it is related with the viewing geometry of MODIS. We replace "data" with "pixel" and hope reviewer can accept it.

18. Line 134: Reformulate (or at least remove *"Thus"*): *Thus, temporal and spatial collocation of the radar, MODIS and AHI data is critical to facilitate effective comparison and evaluation*. Note that temporal and spatial collocation is necessary regardless of data coverage, FOV (Field Of View) differences, or repetition frequencies. It might be more straightforward in the case of similar FOV and repetition frequencies, though.

    Yes. We agree. "Thus" is removed.

19. Line 148-149: I do not understand the first part of this sentence: *"According to the climatological distribution of clouds, the ground-based CTH measurements from the Ka radar were averaged within 10 min of the MODIS observation time (±5min) in this study"*. Please reformulate.

    This sentence is modified. More details are given in the replies to the following comment.

20. Line 149-150: Note that averaging data in time or space is optional. (In Håkansson et al. we successfully used nearest neighbor matching between CloudSat (CPR) radar data and MODIS collection 6 data). And note that your method, using all MODIS data within 5km and 10min of radar data instead of nearest MODIS 1km pixel and 1.7 minutes of radar data, might decrease the part of imager data actually seen by the radar. The effect would depend on the horizontal resolution of the radar which is unknown to me. A motivation for the averaging of the MODIS data should be included.

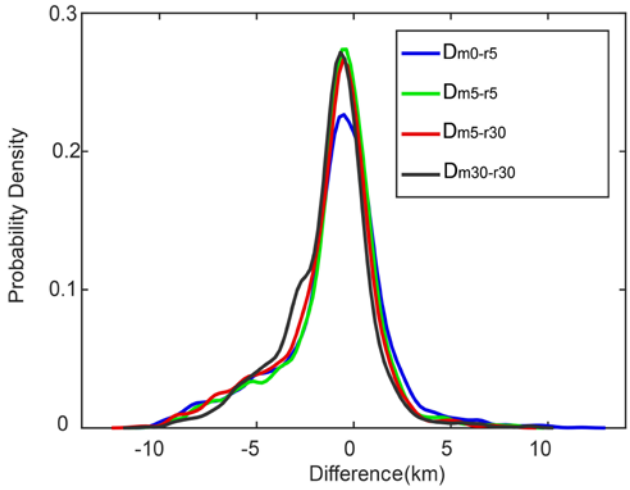
    Aqua flies ahead of CloudSat by about 1.5 minutes, like a train. The footprint of CPR is enclosed by the footprint of MODIS. It is appropriate to use the nearest neighbor matching method for the comparison between MODIS and CPR.

    Our Ka-band radar is stationary. In vertically pointed mode, clouds moving into radar's transmitting beam (width $0.4°$) are explored. The length of a scanning "path" by radar is determined by the measuring time, ranges (equals to the height in vertically-pointed mode) and the moving speed of cloud. Then the detecting length, namely horizontal resolution, is flexible. For example, if the speed of a moving cloud is 10 km/h, KPDR takes about 6 min for 1 km and about 30 min for 5 km.

    On the other side, the 1-km spatial resolution of MODIS is appropriate for the data around sub-satellite point. The area of a MODIS pixel is variable and normally increases as the distance to the sub-satellite point increases. As shown in Fig.2, a MODIS pixel covers different areas due to different viewing geometry of MODIS. Then the nearest MODIS data to radar site has various distances. Comparison based on one nearest MODIS pixel will suffer big risk. The nearest neighbor matching method is inappropriate for data collocation of MODIS and ground-based Ka-band radar. Collocation based on more pixels within a certain area and more profiles benefits reducing the risk. That is why there are so many previous works did not use the nearest pixels for the comparison with ground-based radar.

    In fact, we have investigated which time-space collocation scheme is the best for the comparison between MODIS and Ka-band radar. This work has been involved in a submitted paper which now is under reviewing. Here we cite one figure from the paper to illustrate briefly.

    The figure below presents the statistics of the differences using four different collocation methods for the MODIS and radar data: radar 5 min vs. nearest MODIS ($D_{m0\text{-}r5}$), radar 5 min vs. MODIS 5 km ($D_{m5\text{-}r5}$), radar 5 min vs. MODIS 30 km ($D_{m5\text{-}r30}$), radar 30 min vs. MODIS 30 km($D_{m30\text{-}r30}$). It is found that the $D_{m5\text{-}r5}$ is close to the averaged difference of four collocation methods.



In this manuscript, we omit the detailed descriptions of relevant studies considering the sentence balance between AHI and MODIS and hope reviewer can accept.

21. Line 144: *"These collocation methods were designed to match the research goal."* Reformulate to make it sound less as researchers are designing experiments to achieve before-hand determined results. Researchers will make best effort to choose as sound settings as they can. Averaging in time and/or space can improve the study (for example maybe decrease effect of outliers), but can also introduce new problems. For example in situations with clouds of two heights averaging will introduce new types of clouds not present in the original data.

    Sorry for that. It is revised as "These collocation methods were designed to satisfy different instrument and observation conditions."

22. In Figure 2: Please note with a different marker (for example x) which MODIS pixels where included in the averaging for each case. Also make the size of the radar dot match the field of view of the radar if it does not already.

    Figure 2 has been revised according to reviewer's suggestion.

23. Equation 4: Reformulate or split to two separate equations. Now, because of the parenthesis the reader get the impression the MODIS height H_m is a function of the AHI height H_a. A formulation like $D_{mr/ar} = H_{mr/ar} - H_r$ would be better.

    The equation has been separated.

24. Line 170: How was the poor quality data defined? Which data were of poor quality MODIS, radar or both? Please clarify.

    In fact, the "poor quality" is used to refer to those MODIS data out of valid value range. They have been deleted since the meaning of sentence what we want to tell does not change.

25. Line 173: Nice to see these statistics suitable for non-Gaussian error distribu- tions: *"Among all comparisons, about 14% differences were less than 0.25 km, 27% were less than 0.5 km and 49% were within 1.0 km."* In Håkansson et al. we found for, MODIS collection 6 compared to space borne CloudSat (CPR) *radar data, the part of errors higher than (0.25km, 0.5km and 1km) to be (84%, 70% and 48%). This would correspond to (16%, 30% and 52% of comparisons with in 0.25km, 0.5km and 1km. Considering that our investigation was global and with a space borne radar compared to this investigation using a ground based radarat a single point I think results are noticeably similar.*

    Yes. Our results are very close. We add some sentences to state the similarity.

26. Line 181: First I was confused as I did not understand you were splitting results into high low with respect to MODIS CTHs in this sentence. I assumed you would use the radar CTH. But now I understand and the result makes sense as the difficult thin high clouds would have a high chance of ending up as MOIDS low clouds. Please make clearer.

    Yes. It is what reviewer understood finally. We revised the abstract and this paragraph, and hope the reader can understand it.

27. Line 205: Cloud occurency frequency. Would *radar cloud fraction* be a better description? The definition is a bit unclear and could be improved. What does cloud time mean? What is observation time? Is it correct that COF = number of radar cloudy profiles divided by the total number of radar profiles (within the 10min time window)?

    Yes. It is what reviewer means. Sorry for our poor language usage. This sentence has been revised.

28. Figure7-b: Should it be bias in the legend of the red line? Please include also medians in Figure 7-b.

    Yes. Sorry for our carelessness. We modify Fig.7, add the figure of the distribution, the median and IQR.

29. Figure 8 and Figure 9: Please note that it is AHI COTs that are used also in the figures.

    We add such expression in the caption of Fig.8. We revise Fig.9 according to reviewer's comments here and above.

30. There are many results in the text; one or more tables giving an overview of the results would help the reader.

    We add Table 3 in the manuscript to show all quantified difference.

31. Line 236 and Line 281: *"Statistically, the AHI retrieval algorithm showed better performance for multilayer clouds than single-layer clouds"*. Better performance for multi-layer clouds compared to single-layer clouds is the opposite of what would be expected for any CTH algorithm. This means that strong evidence is needed to support such a claim. Note that bias is better for multilayer clouds but STD is higher. So there is no support for the claim that AHI would retrieve more accurate CTH for multi-layer clouds compared to single-layer clouds. Please reformulate.

    We delete this sentence according to review's comment. The median and IQR are added.

32. Line 237: *Compared with MODIS, the AHI retrieval algorithm showed a slightly better performance for multilayer clouds.* Can these numbers really be used to say one algorithm is better than the other? If I understand correctly, in these investigations it is not only cases where all three instrument match (AHI, MODIS and the radar), instead there is one data set with all MODIS-radar matches and another with all AHI-radar matches. And there are only 210 multi-layer MODIS- radar matches which is a quite small sample size. And this means that the population bias of all multi-layer clouds actually can be quite different from the sample bias (-1.23km) calculated on 210 samples. A difference between sample bias and actual bias in the order of $2.6SD/(210^{1/2}) = 0.5km$ is very well possible. Therefore I think there are not enough results to support the claim that AHI perform better than MODIS for multilayer clouds. In my opinion all three datasets should be matched, or/and the differences between the distributions

(or the number of samples) need to be larger in order to form enough support for the claim. Please reformulate or update with a statistical test supporting the claim.

Yes. The comparison datasets are different. We agree with the reviewer, especially after we calculated the median and IQR of the difference. We deleted this sentence in the manuscript.

33. Line 237-238: Use COF defined on line 205.

It is revisese.

34. Line 241: Is it as in the other investigations: MODIS data are averaged and for AHI the nearest pixel is used?

Yes. Relevant texts are revised to make the meaning clear.

35. Line 243: Please include also median differences.

Median difference has been added.

36. Line 256: As the error distributions are non-Gaussian I would be very cautious to recommend using bias and STD in any meteorological application.

The median and IQR are added.

37. At least add median to Figure 10. The difference between bias/and median at least show if the distributions are skewed. Even if the high kurtosis of the error distributions would still be hidden.

The median and IQR are added in Fig.10.

38. Line 268: Note that all CTH algorithms do not include radiative transfer models. Or maybe they do, at least implicitly? Please motivate or reformulate.

The "passive satellite sensors" are replaced with the "AHI" and "MODIS" , ensuring an accurate statement.

39. Line 272: At least include also median.

We removed the words " by .....km" since mean and median difference are different and they have been presented in Table 3.

40. Line 284: It is not certain that MODIS had the lowest accuracy in spring. It had the lowest bias (but bias is not the same as accuracy, especially not for non–Gaussian distributions!). Note that also standard deviations were low for MODIS in spring which would indicate better accuracy. If you want to use a single measure to evaluate the accuracy of the algorithms I would recommend mean absolute error. Please update.

According to reviewer's comment, this statement is removed.

41. Figures showing the distributions for D_{ar} and AHI-MOIDS should be included. Similar to the one for D_{mr} in Figure 4-b.

The distribution figures have been added in Fig.7 and Fig.9

3 Technical corrections

Line 231: “might due to” => “might be due to” or maybe better “could be caused by”

It has been revised.