**Anonymous Referee #2**

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The manuscript describes an algorithm for discriminating clear-sky from cloudy-sky scenes using an infrared thermometer (IRT). The objective of the study is to distinguish sky scenes in the field of view of a microwave radiometer (MWR) to improve the calibration of the MWR and better quantify uncertainties in MWR retrievals, both of which are influenced by the presence of clouds. The described algorithm utilizes both temporal and spectral approaches, both of which have been used by previous studies. The algorithm is validated qualitatively using satellite imagery and case studies, and quantitatively using a co-located ceilometer. The results suggest the algorithm performance is similar or better than previous studies.

The manuscript is appropriate for AMT because it presents a practical method that is broadly applicable to the global network of MWRs that are not necessarily installed alongside a sophisticated suite of sensors that can provide detailed cloud observations. However, I have a number of general and specific comments that should be addressed.

*It is really appreciated for the careful reading and constructive suggestions made by the referee. Thanks to the review, many points are clarified and new perspectives are added, resulting in a much improved manuscript. Please note that the author's response to the referee's comments are given in green italic.*

General Comments:

(1) The main point of general interest is that the method is broadly applicable. Thus, the authors should show that it is valid in other environments, which may be colder and drier, warmer and wetter, cloudier or clearer. For example: How do the detection limits of the IRT influence its usefulness elsewhere?, How does the fractional cloud cover of a location influence the amount of time required to build enough statistics for calculating coefficients?, Are locations that are distant from reanalysis assimilation sources susceptible to error because of uncertainties in local representation of the atmospheric state?

⇨ *Applicability of the current algorithm (or approach) to the other environments could be tested with data obtained at different environments such as from ARM* *sites. We are currently investigating the feasibility and the results will be reported in a separate paper. On the other hand, the study location is located at the mid-latitude with the distinct four seasons, cold and dry winter, mild spring and autumn, and hot and humid summer. Thus, although all of the extreme climates such as extremely cold and dry arctic or extremely hot and humid tropics are not included in the measurement data, much of the atmospheric variability is considered to be there. The table below shows the monthly mean POD showing an insignificant temporal variability which indirectly demonstrates the stable performance of the new algorithm for the different sky conditions. (1 to 3 is for the winter condition, 4 and 5 are for spring, and 6 is for the summer condition)*

⇨

| Month | Total | Hit | False alarm | Misses | Correct negative | POD |
|---|---|---|---|---|---|---|
| 1/2013 | 40965 | 9498 | 1526 | 2774 | 27167 | 89.5 |
| 2/2013 | 39371 | 14812 | 2634 | 1830 | 20095 | 88.7 |
| 3/2013 | 39616 | 9180 | 3525 | 2315 | 24596 | 85.3 |
| 4/2013 | 38803 | 13940 | 3333 | 458 | 21072 | 90.2 |
| 5/2013 | 39501 | 14141 | 3136 | 704 | 21520 | 90.3 |
| 6/2013 | 39707 | 21201 | 5397 | 292 | 12817 | 85.7 |

⇨ *Please refer to the author's responses to other comments which are specifically commented by the referee.*

(2) The introduction points out deficiencies in techniques similar to the proposed method (e.g., false positives from aerosols, and false negative for scenes containing thin cirrus). The authors state that the new algorithm performs as well or better than similar methods from previous studies. It would be helpful for the authors to describe what characteristics of the new method are responsible for the improvement and whether they have made any advancement from the problems faced by previous methods.

⇨ *The main reasons for the improvement are two folds. Number one is the use of the predicted clear sky Tb which is derived from the location-specific empirical formula and sensor-specific criteria for the temporal variability of the clear sky*

*Tb. The other one is on the bandwidth of the current IRT which is narrower than other broadband instruments. Thanks to the band selection, atmospheric signals such as from inversion, water vapor, haze are much smaller than that of the clouds. However, it should be noted that the there was no severe Asian dust events during the study period and thus the demonstration should be waited until the event occurs.*

⇨ *The responses are reflected in the Summary section (9433L23), "..for certain situation. This is achieved mainly by the application of the predicted clear sky Tb which takes into account of location-specific relationship between surface weather data and Tb, and by the application of sensor-specific criteria for the temporal variability of the clear sky Tb. The other reason for the improvement is on the bandwidth of the current IRT, narrower than other broadband instruments, which amplifies the cloud signal over the atmospheric signals such as from inversion, water vapor, haze. However…."*

**Specific Comments:**

**Introduction**

(1) 9415L10-12: Is there a reference for these uncertainties?

⇨ *The sensitivity of the measured downwelling radiation in the microwave region due to the clouds is shown by many authors. One representative publication is cited in the revised manuscript. Any further recommendation is welcomed.*

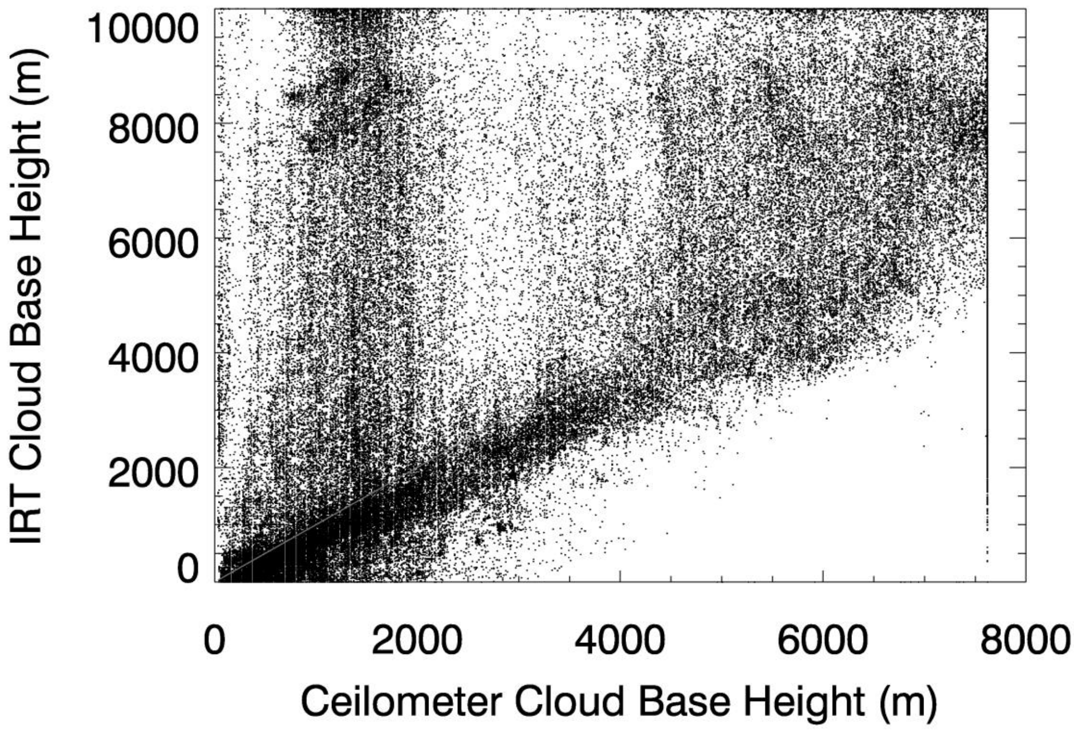
Cadeddu, M. P., and D. D. Turner, 2011: Evaluation of water permittivity models from ground-based observations of cold clouds at frequencies between 23 and 170 GHz. IEEE Trans. Geosci. Remote Sens., **49**, 2999–3008, doi:10.1109/TGRS.2011.2121074.

(2) 9416: I believe the IRT is an optional accessory for RPG MWRs. If this was the case for the IRT used by the study, the authors might consider pointing this out in the introduction, as it highlights a very practical reason for focusing on the IRT and the method's applicability for future studies.

⇨ *Indeed, it is an optional accessory for RPG MWRs, and it is specified in the description of IRT instrument.*

(3) RPG software may (??) provide some cloud detection information using the IRT (if installed). If this is so, can you clarify why the proposed algorithm is preferred over RPG cloud flags?

- ⇨ *That is a very good question and the answer is "yes", indeed RPG software provides information on the cloud base height which could be used to detect the cloud presence. On the other hand, when the cloud base heights from the RPG software and the collocated ceilometer is directly compared, as shown below, it is very difficult to determine a practical way to utilize the default product. Although there seems a one-to-one relationship between the two data, it is hard to figure our any consistent relationship. We think that some of its variability could be explained by the uncertainty due to the vertical temperature profile used to infer the cloud base height for the IRT measurement (purely guessted), although a large portion of the variability shown in the diagram is hard to explain.*




*< Comparison of cloud base height obtained by the RPG software and ceilometer observation obtained for about 8 months (September 2012 to June 2013). The vertical line*

*appeared at the 7620 m of ceilometer axis is due to the detection limit of the ceilometer>.*

(4) 9416L27: It isn't clear if the study adopts one or more previous methods for use with the IRT or improves upon previous work. Is the scope of the manuscript to improve upon previous work or to draw from previous work in order to develop a method applicable to the network of MWRs?

- ⇨ *The latter one is the intention of our paper. The two new sentences are added at the last phrase of the Introduction to reflect that point more clearly; "Thus the new algorithm combines both temporal and spectral characteristics used separately or independently in the previous studies, with the dynamically determined threshold values for the separation of clear and cloudy sky."*

**Section 3**

(5) 9421L18: I don't understand the use of "extensive" here. Please remove or clarify.

- ⇨ *Removed*

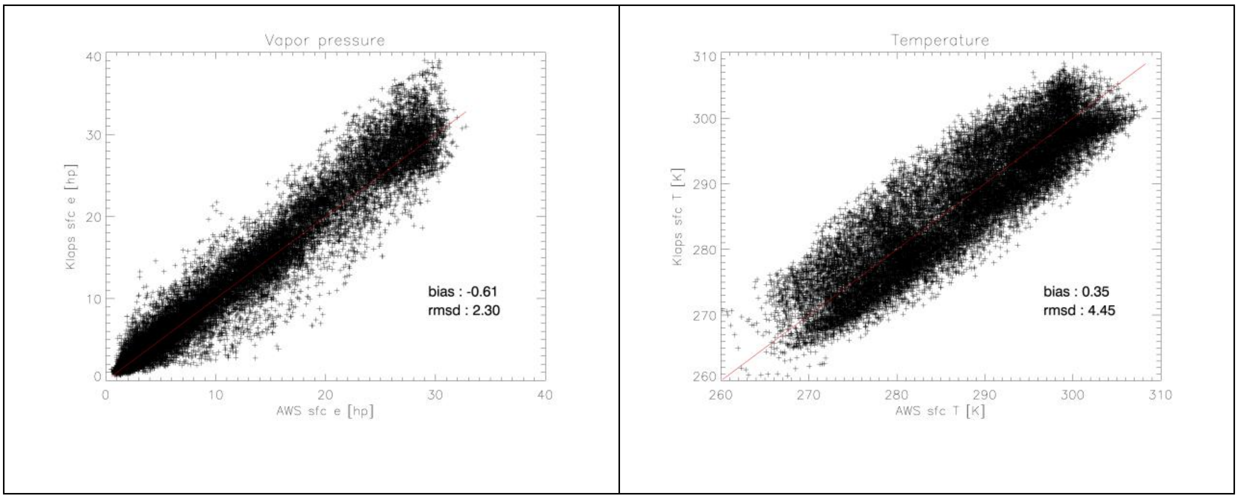
Section 3.1

(6) $^{o}$C are used sometimes (e.g., Fig. 3) and Kelvin is used at other times (e.g., discussion of Fig 3). Please choose one or the other for clarity.

- ⇨ *Used $^{o}$C.*

(7) TbKLAPS is from the reanalysis, while Tsfc and e are measurements. (a) How were the KLAPS data representing the location of the measurements acquired (e.g., linear interpolation) and what is the native spatial resolution of KLAPS? (b) How do Tsfc, KLAPS and eKLAPS compare to Tsfc and e, as this could be responsible for some of the RMSE in Figs. 4 and 5, or potentially, a bias later on (Eq. 4 may account for potential discrepancies between the reanalysis and surface meteorology – please clarify).

- ⇨ *(a) The native spatial resolution of KLAPS is 5 km. Thus, the data used for the simulation is obtained by taking the average of the four grid points surrounding the weather station. The variability of the four grid points are insignificant.*
- ⇨ *(b) First of all, the figures below compare $T_{sfc}$ and vapor pressure e from the KLAPS reanalysis and the AWS measurement. The scatter plots basically represent the accuracy of the KLAPS surface weather data.*




*Comparison between the surface vapor pressure (left) and surface temperature (right) between the KLAPS reanalysis and AWS observation.*

⇨ *Indeed the variability shown in Figure 4 and 5 could be partly due to the difference between the model surface weather data and actual observation data and partly due to the atmospheric variability (different vertical profiles etc.). On the other hand, it is quite a difficult to quantitatively separate the two effects, Thus, a new sentence, reflecting this observation is added; "…accuracy of $Tb^{P}_{clr}$. The uncertainty is mainly from the difference in the surface weather data used for the $Tb_{KLAPS}$ simulation with the actual surface weather data (rms difference for $T_{sfc}$ and e is 4.45 $^{o}$C and 2.30 hpa, respectively) and the variability of vertical profiles of temperature and humidity. Nevertheless, the…."*

(8) 9422L24-25: The subscript "KLAPS" needs to be added to the appropriate variables in Fig. 4 and caption.

⇨ *Corrected. The diagram is replaced with the corrected one.*

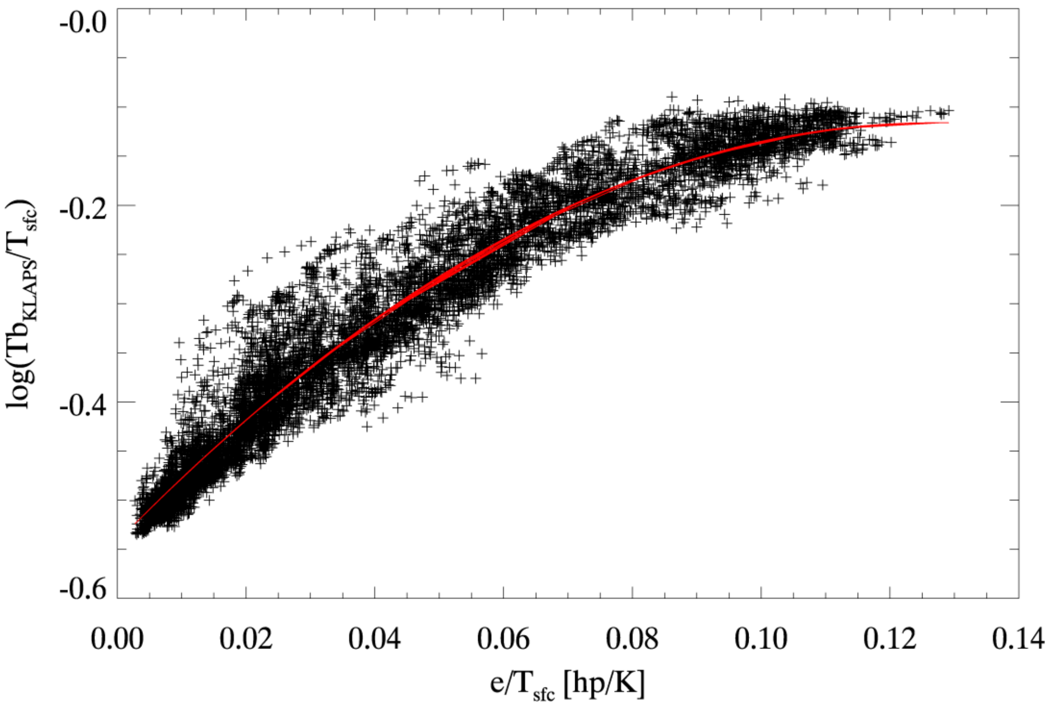
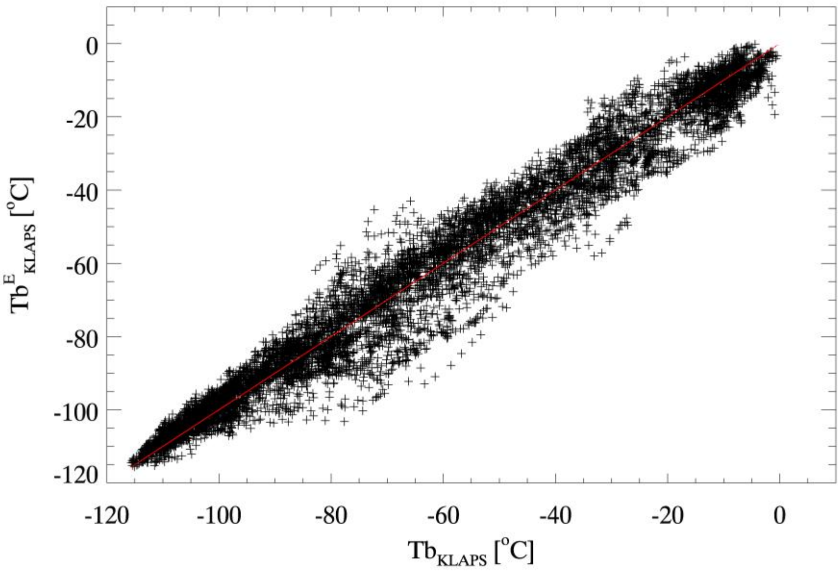



*Figure 4. Simulated relationship between the ratios of brightness temperature to the surface air temperature ($Tb_{KLAPS}/T_{sfc}$) and the ratio of water vapor pressure to the surface air temperature ($e/T_{sfc}$). The numbers of data points are 8760 (hourly data for one year). The $Tb_{KLAPS}/T_{sfc}$ value increases rapidly with the increase of $e/T_{sfc}$ due to the increased contribution of surface air in the downwelling radiation. When the $e/T_{sfc}$ value reaches about 0.09, the $Tb_{KLAPS}/T_{sfc}$ value does not vary significantly because the wavelength region is the atmospheric window region (contribution from upper air is always there).*

(9) TbPclr and TbEKLAPS appear to be used interchangeably in this section (e.g., Fig. 5 labels vs. Fig. 5 discussion 9423L9-18). Please ensure they are clearly distinguished.

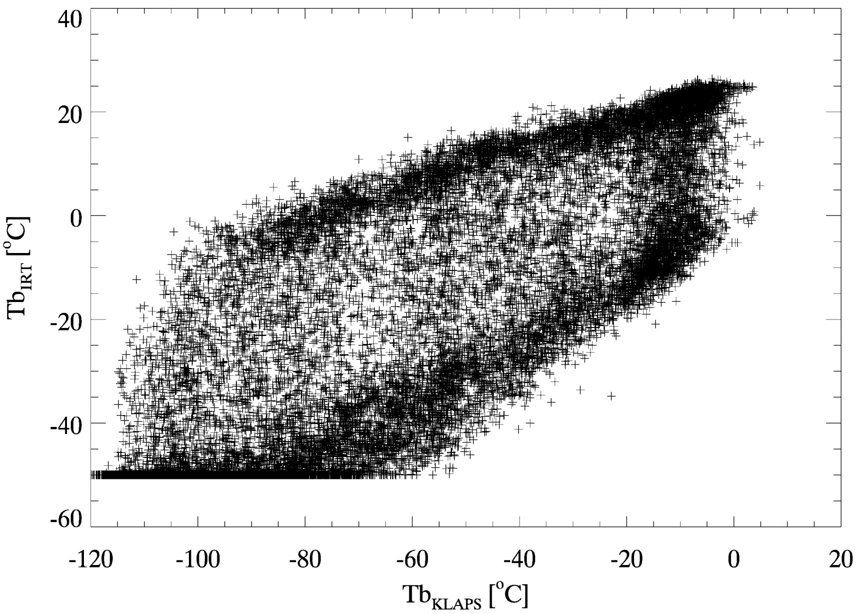
- ⇨ *It's been clarified. The confusion comes from the incorrect labeling of Fig. 5 which should look like below;*



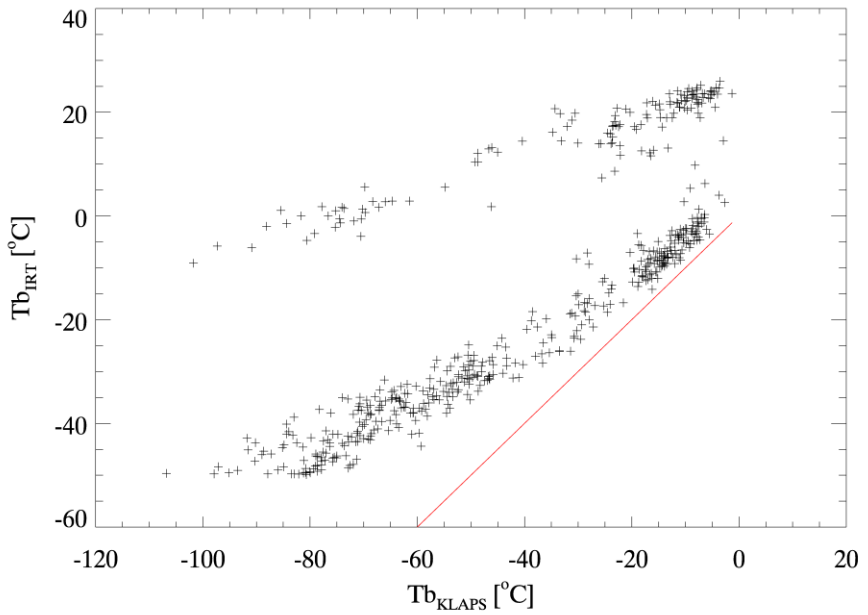

(10) Figure 6: (a) Please consider showing the one-to-one line for the clear-sky. This will help show the range of Tb where KLAPS and IRT are in agreement. (b) Please make the x-limits the same in Figs. 6a and 6b.

- ⇨ *Corrected. The new plots look like;*

(a)




(b)




⇨

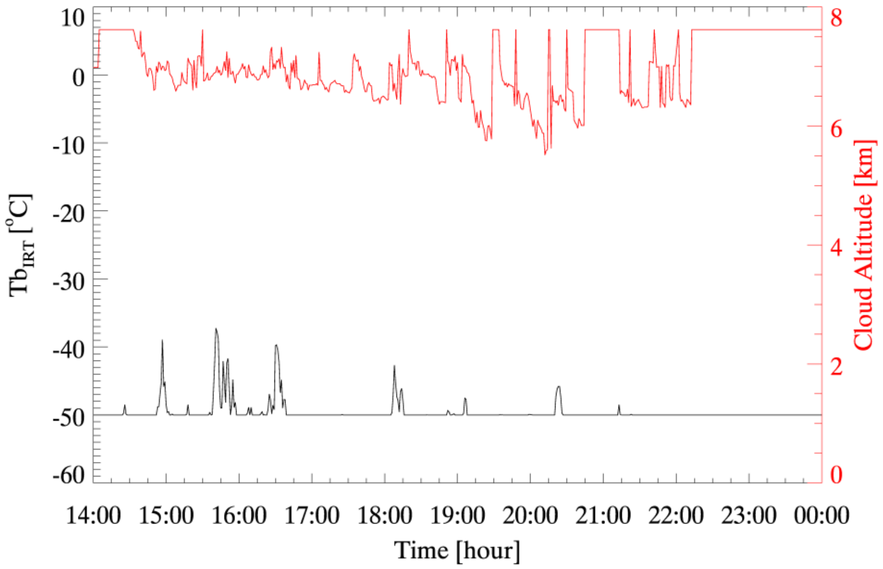
(11) 9424L17-18 & Fig. 6: The fact that there is an increasing systematic difference between TbKLAPS and TbIRT with decreasing temperature for the clear-sky condition (i.e., they don't fall along a 1-1 line) seems important. Could this suggest error in the IRT at low sky brightness temperatures (not just the mirror, but also maybe poorly suited calibration at low values)? Could it instead be an expression of potential systematic differences between KLAPS and the surface meteorology (i.e, Tsfc, KLAPS and eKLAPS compared to Tsfc and e), which were not discussed (see comment #7)?

⇨ *First of all, as shown earlier, no significant systematic differences in the surface weather data between KLAPS reanalysis and AWS are found and it should be concluded that that kind of difference could not introduce such an increasing systematic difference between $Tb_{KLAPS}$ and $Tb_{IRT}$ as shown in Fig. 6. Thus, the systematic difference is considered to be rather due to the uncertainties in the absolute calibration of IRT at the lower Tb value, or reflector degradation. With this, we added a few words at the end of 9424L18; "....be related to the uncertainties in the absolute calibration of IRT"*

(12) The fact that the IRT does not measure below -50 C is very important for this section, but this problem is not discussed. (a) How does the algorithm classify scenes when the TbIRT limit is reached? (b) For TbKLAPS < _ -60 C (corresponding to the IRT limit) there is a loss

of sensitivity to optically thin clouds, but there is not enough information to determine how severe this loss of sensitivity is, or any discussion of how it might impact the use of the algorithm for better characterization of MWR data.

- ⇨ *Yes. The limitation in the dynamic range of the current IRT, too warm for the lower boundary, is probably the most significant limitation of an extensive application of the current version of IRT for the detection of clouds having cold temperature (high altitude or extreme cold situation). Our answers to the specific questions are*
- ⇨ *(a) When the measured $Tb_{IRT}$ equals to -50 $^{o}$ C, the algorithm classifies it as the clear sky due to following reasons. First of all, as $Tb_{IRT}$ does not vary significantly during one minute, the temporal variability is very small, resulting in the classification of a clear sky. Secondly, the predicted clear sky Tb could be colder than -50$^{o}$ C for a cold and dry atmospheric conditions. However, due to the used threshold value is rather relaxed, the measured $Tb_{IRT}$ of -50$^{o}$ C is rarely identified as cloudy. Thus, among the total of 65147 cases of -50$^{o}$ C of $Tb_{IRT}$ during the validation period, all of them are classified as the clear sky.*
- ⇨ *(b) For a quantitative assessment of this limitation, the number of cloudy cases (identified by the ceilometer) among the 65147 cases are checked. It was found that a total of 3773 cases are identified as cloud, although the algorithm classified them as clear sky, resulting in "misses". As shown in the Table given in the response to the General comment (1), the number of "misses" during the winter months (Jan., Feb., March) are much more than the other months mainly due to this limitation. A careful inspection of time series during such an event, as shown below, the optically thin high clouds detected by ceilometer has variable temperature effects and most of them are not detected by IRT.*




*<Time series of $Tb_{IRT}$ and cloud altitude estimated by the ceilometer on Feb. 04, 2013. The current algorithm classifies all -50$^{o}$C data as clear sky>*

⇨ *As these "misses" are mainly due to the high altitude thin clouds, their effects on the downwelling radiances at the microwave region is not significant and thus its effect on the characterization of MWR data would be minimal*

⇨ *Based on the referee's comment and our responses, we added a few more sentences in the revised manuscript.*

⇨ *First of all, at the end of the description of the IRT data (9418L20), "The effect due to the limited accuracy below -50$^{o}$C on the algorithm performance is mainly in the under-detection of the cold clouds and is further discussed in the validation section", is added.*

⇨ *And then, at the validation section, a new phrase is added, followed by the phrase for the "false alarm"(9431L13), "On the other hand, part of misses is due to the limitation of the dynamic range of the current IRT, having -50 $^{o}$C as the lower boundary. With the current algorithm, the scene with $Tb_{IRT}$ of -50 $^{o}$C is classified as a clear sky because of two reasons. First of all, as the measured $Tb_{IRT}$ at this temperature does not vary significantly for one minute, the temporal variability is very small. Secondly, the predicted clear sky Tb could be colder than -50$^{o}$ C for a cold and dry atmospheric conditions. However, as the used threshold value is* *rather relaxed, the measured $Tb_{IRT}$ of -50$^o$ C is rarely identified as cloudy. Thus, all of the 65147 cases with the -50$^o$ C during the validation period are classified as the clear sky. However, among the 65147 cases, 3773 cases are identified as cloudy by ceilometer which is verified by a careful inspection of time series of $Tb_{IRT}$ and ceilometer data during such an event. When this happens, it is classified as misses and consists of more than half of the total misses (about 6900 cases) during the winter months (Jan., Feb., and March).”*

⇨ *Finally, at the Summary section (9433L18) “…satellite data. On the other hand, among 1/3 of the failures caused by under-detection of clouds by IRT, a large portion is due to the limited lower boundary of the dynamic range, -50$^o$ C, of the current version of IRT. To make….”. And at the last phrase (9434L1), “…the reflector. Furthermore, there seems a large room for an improvement by extending the dynamic range of IRT toward the cooler temperature, especially for the colder clouds. Finally, ….”*

**Section 3.2**

(13) 9425L17-21: The temporal standard deviation is sensitive to the time duration over which it is calculated. The optimal time span is related to the time span over which spatial variability within clouds and between clouds is expressed in time (i.e., how fast are the moving, and what are their spatial characteristics) and cloud height (the spatial footprint in the field of view of the IRT). How sensitive are the results to the choice of the time span?

⇨ *We agree with the referee’s view on the characteristics of the temporal standard deviation and its importance on the algorithm performance. We also consider that this is an important point to be investigated further. On the other hand, it would be always better if we use data obtained for a shorter time span to check the temporal variability induced by the cloud presence which gives a drastically different Tb value. The cloud signal is so significant that whenever a single cloudy data is included in the time averaging period (for a reasonably short time span), the estimated standard deviation is a way above the representative value for the clear sky conditions. Thus, in view of the increasing possibility of viewing clear sky condition and a better algorithm performance, it would be better if we use shorter time span than one minute. However, as described in the manuscript, we limited the time span to one minute for the three reasons, available data for* *the validation and the algorithm input while keeping the high temporal resolution of the original data.*

(14) 9426L6: What is meant by "compactness"?

⇨ *Meant variability*

**Technical Corrections:**

⇨ *The corrections pointed out by the referee are properly reflected in the updated manuscript.*

9419L26: "To have an enough number of" => *It is removed, and following sentence is modified to "A total of 8,760 vertical profiles corresponding to a one year time period containing the atmospheric variability of the four different seasons is utilized."*

9420L3: "…profiles are cloudy free…" to "…profiles are cloud free…"

9420L16: "fog, density" to "fog, and density" => *"fog, and the atmospheric density"*

9422L20: "interested variable" to "variable of interest"

9424L23: "relationship" to "the relationship"

9425L10: "condition" to "conditions"

9425L13: "are" to "is"

9426L20: "One of plausible cause of this…"=> *"One of the plausible causes of this…"*

9430L5: "cloud based" to "cloud base"

9424L18: Perhaps replace "spreadness" with "variability" => *variability, indeed.*

***A few other corrections made by authors'***

- *Location of the weather station was before its movement. Currently it is (35.17° N, 128.57° E, 37.15m above the sea level).*
- *9424L1: "..widely distributed…" => "…widely scattered…"*
- *One of the author's name is changed to her preference (H.-Y. Won => H. Y. Won)*