Review of manuscript: “acp-2015-661”

The paper isolates and quantifies the scattering effect of ice hydrometeors in predominantly ice clouds on measured microwave brightness temperatures at the Summit station in Greenland. The scattering signatures are also compared with those obtained from a radiative transfer model.

I found the paper very interesting and well written. Here are a few minor points that in my opinion necessitate more discussion.

Pettersen *et al.*: Thank you for the time spent on your thoughtful review and questions and comments. We are glad that you find the work interesting. We will attempt to address your points below (R# is the reply to the comment and M# is the changes made to manuscript if applicable):

1) In Fig. 2, 4, and 5 the plot bar with the number of counts is missing. It could also be expressed as a percentage of the total number of observations. I think it will show that the number of cases where the ice signature is detectable in the 90 GHz channel are very limited. Therefore I don’t think the ice effect will alter the overall statistics of the retrieval performance. Of course if one is analyzing specific cases it is important to correctly model the propagation by including the effect of ice.

R1) We agree that the number of cases where the ice effect causes an issue with the retrievals is small and should not alter the overall climatological statistics of the PWV and LWP. We attempt to stress this point in the conclusion section (see page 19, lines 20 – 23). However, if one subsamples only the precipitating ice cases the retrievals values may be an issue.

We agree that plotting Figures 2 and 5 with a percentage (normalized) colorbar is useful (see new Figure 2 and 5 at the end of this document as well as in the revised manuscript). Figure 4 shows the response of only the low frequency MWR channels to the correction and has color contours with a count threshold described in the caption so we prefer to leave this figure as is.

M1) Please see new Figures 2 (page 27) and 5 (page 30) in the manuscript with colorbars of percentage normalized counts. Edited captions of both figures (see Page 27, lines 5 – 6 and Page 30, lines 6 – 7).

2) Was the same dataset used In Fig. 2 (a,b) and Fig. 4 (c,d)? Fig. 2 shows a maximum Zpath ~ 10^5 while in Fig. 4 is $6x10^4$. Or may be it was just truncated in Fig. 4?

R2) Yes, the same dataset was used in Figures 2 and 4. Figure 4 the y-axis is purposely truncated to highlight the change in slope from the correction in the low Z_{PATH} cases – the cases with lower ice optical depth where the low frequency MWR channels are insensitive to the ice. We added a note about the truncation of the y-axis in the Figure 4 caption.

M2) Clarification of the y-axis limits in Figure 4 caption (Page 29, lines 6 – 7).

3) In my personal opinion Fig. 3 is not really necessary for the understanding of the effect of ice in the retrieval. However I'll leave this to the author to decide.

R3) We are happy to hear that the text explanation of the LWP and PWV correction was clear (we thought that was a difficult point to explain), so thank you for this comment. We would prefer to leave the figure in the paper, as we believe that this correction is perhaps non-intuitive for readers less familiar with these types of retrievals and the figure may aid in understanding the correction.

4) In Fig. 5 what is the range of brightness temperatures for these cases where Zpath > $\sim 10^4$?

R4) This is a good point to highlight and is illustrated somewhat clearer in Figure 6: For Z_{PATH} of $\sim 10^5$ mm^6/m^2: in the 90 GHz channel the range of BTs is about 2 – 7K. For the 150 GHz channel, the range of BTs is about 10 – 30K. And for the 225 GHz channel, the range of BTs is about 20 – 50K. We do say in the text: "At the highest observed Z_{PATH} values (about 10^5 mm^6/m^2 and larger), BTs are enhanced by about 7 K in the 90 GHz channel and 30 K and higher in the 150 GHz channel" (see Page 16, lines 5 – 6), but this only references the maximum BTs. We clarified this language to stress that there are a range of BTs for a given Z_{PATH}.

M4) Clarified comments, see Page 16, lines 5 – 6.

5) In Fig. 5 it seems that all measured BT's have a positive bias with the model, which is independent of the presence of ice and may be due to (may be?) calibration. Is this a clear-sky bias? For example if I look at the 150 GHz frequency it seems that until Zpath < $\sim 10^4$ all observations lay around ΔTb $\sim$+2 K +/- 2 K. It may be visually helpful to subtract this bias so that the plots are centered around zero when there is no ice effect.

R5) You are correct that this is a clear-sky bias. An analysis of observed minus computed downwelling radiance in clear sky scenes shows a seasonal dependence to this bias (with the mean bias over the annual cycle being about zero), but that the magnitude of the bias is always smaller than the radiometric uncertainty of the observation. However, since our analysis uses data from primarily the summer season, this results a positive bias in these channels. We are unable to determine if this (small) bias in the channels is due to calibration uncertainty in the radiometer or forward model error. In the lower frequency channels (23.84 and 31.40 GHz) it is negligible (see Figure 2a and b). In the 90, 150, and 225 GHz the clear-sky bias is ~0.5, 1.3, and 1.9K, respectively. Since this is a systematic bias within the radiometric uncertainty, we would prefer to keep the figure as is and not subtract out the bias. We prefer to leave the figures plotted as is, but added a comment about the clear sky bias in the caption.

M5) We added detail about the clear sky bias in the caption for Figure 5 (see Page 30, lines 12 – 16).

6) Referring to my previous comments, in Fig. 6 however the ΔTbs appear unbiased. Is this just a visual effect?

R6) We believe that this is a visual effect, because in Fig. 6 the points are colored by the average Z_{PATH} within the bin, not the number of points within the bin. Therefore the clear-sky biased "bullseye" is not obvious in the figure. The same BT difference data is used in these multi-frequency plots, but the occurrence is not shown.

7) In Fig. 5 It appears that there is a non-linear increase of ΔTb when Zpath > 10^4. In other words Zpath saturates around 10^5 but ΔTbs keep increasing. For example at 90 GHz when Zpath is near its maximum ΔTb can be anywhere between 5 and 15 K. Is this effect due to differences in the vertical distribution of the hydrometeors?

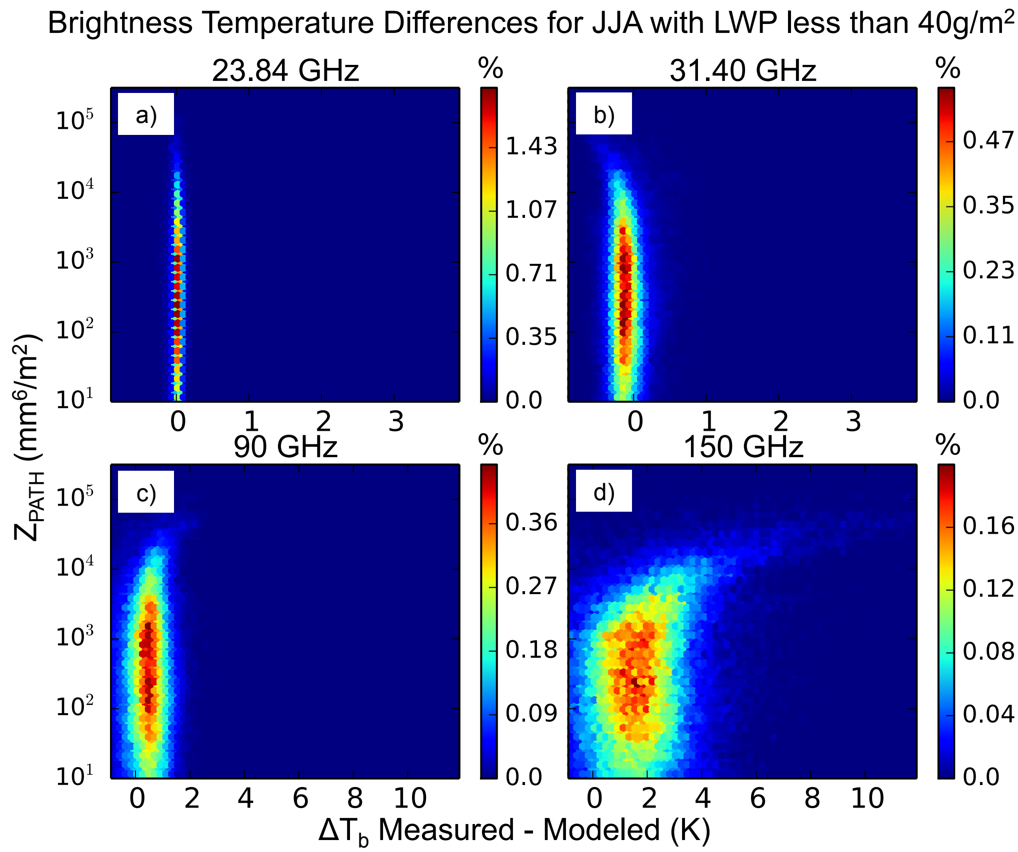
R7) We think this is a very reasonable hypothesis, however to try verify this using models, we need accurate particle size distributions representative of Summit, Greenland. The large range in the passive microwave signature is likely more related to variations in the ice crystal habits and particle size distribution, rather than the vertical distribution on its own. The ice crystal sizes and habits change as they move vertically in the column (due to cloud dynamics, growth processes, etc.), so these effects are difficult to model and beyond the scope of this work.

8) The author identifies the selected clouds as precipitating, however it is not clear how the hydrometeors are modeled in the radiative transfer model in section 5.4. It seems that in the model the hydrometeors are located in the cloud and the ice is assumed to be cloud ice content with no precipitating ice content. In other words, how is the profile of ice mixing ratio defined? Could it be that if the hydrometeors are entirely located in the cloud it may take a higher IWP to produce the same brightness temperature of a precipitating cloud? I think that the vertical distribution of the scattering hydrometeors will have a major effect on the model result as it appears to be based on Fig. 5 (see comment #7).

R8) This is a good point: we make no distinction between precipitating ice and cloud ice in this study and have clarified this in Section 5.4. The Field *et al.*, 2007 size distribution is temperature dependent, so it forces a particular relationship between the Z_{PATH}, passive microwave signature, and the IWP. If the microwave extinction optical depth is held fixed, then the calculated IWP does tend to increase as the temperature drops, because of the shifting of the Field *et al.*, 2007 size distribution towards smaller particles, though that relationship may not hold for all temperatures and ice crystal habits.

M8) See Page 18, lines 8 – 10.

New Figure 2 – with colorbars expressed as a percentage of total number of observations for each MWR Channel:



New Figure 5 – with colorbars expressed as a percentage of total number of observations for each HFMWR Channel: