Anonymous Referee #2

Received and published: 30 December 2015

This study explains the radiometric signatures observed across a wide range of frequencies (~20 - 225 GHz) and by both active (cloud radar) and passive (microwave radiometer) sensors. To make everything physically consistent, the authors have to improve (modify) existing liquid water retrieval algorithms to account for the influence of ice at high frequencies. By identifying the major contributors to the observed signatures, I think that this study laid the groundwork for future use of all these radiometric data in cloud ice/liquid water retrievals. Therefore, I think this study is valuable and should be published.

Pettersen *et* al.: Thank you for the time and effort spent reviewing the manuscript. We are glad you find the work to be valuable and appreciate your thoughts and comments and will do our best to address them below (R# is the reply to the comment and M# is the changes made to manuscript if applicable):

But I do have the following comments, and would like the authors to address them.

C1) First, reading the paper, I could not find at what level the "liquid water cloud" was placed when the radiative transfer simulations were conducted, and how its relative position to the profile of ice (dBZ) will alter the conclusions. For example, for high dBZ cases, most of ice should be close to surface, whether the liquid water is placed below or above the major portion of the ice in the vertical should change the downwelling brightness temperatures at high frequencies. Did the authors ever do any sensitivity test to see how big this effect is?

R1) For the radiative transfer modeling used to isolate the ice signature from the MWR observations in this study, the cloud liquid water level is defined by the Ceilometer cloud base height (see Section 2.1.3). However, for the SOI simulations that included the ice scattering (see Section 5.4), we did not include the presence of cloud liquid water but only the scattering from the ice and emission from the atmosphere gases (see Page 18, line 10). We edited and added a clarifying note about this in first paragraph Section 5.4. Additionally, we did run sensitivity studies with cloud liquid water path typical of Summit (~40 g/m^2) and see insignificant difference in the simulated enhanced brightness temperature in the HFMWR: the highest Z_{PATH} values at Summit (10^5 mm^6/mm^2) decreased an approximate 1, 1.5, and 4% in the enhanced BTs in the 90, 150, and 225 GHz channels, respectively.

M1) We added a clarifying comment in Section 5.4 (see Page 17, lines 19 – 21).

C2) Second, in the paper, the authors mentioned that the TKC15 liquid water absorption model "improved convergence" in doing retrievals compared to other models. Since two* of the authors of TKC15 model are also co-authors of this paper, is it possible to give the readers more details on "how the improvements are"? I doubt that the other liquid water dielectric models (for example, the Rosenkranz 2015 model) are so different (therefore, switch to Rosenkranz 2015 model would not alter your result), but I could be wrong. But at least, the readers should be let known whether this uncertainty is a factor in explaining the observed signatures.

R2) *Quick correction before addressing the comment: one author of the Turner, Kneifel, Caddedu (2015) study is a co-author in this work (Dave Turner is a co-author; Stefan Kniefel's case study work from the Kneifel et al. (2010) paper was foundational to this study, however Kneifel is not a co-author).

This is a good point and the question of which liquid water absorption model is appropriate to use in this study was addressed in the responses to the initial Quick Reports. This study was originally submitted using the Liebe91 cloud liquid water model and a 4-channel LWP/PWV retrieval (23, 31, 90, and 150 GHz). This is what is currently available in the published LWP/PWV retrievals in the ICECAPS dataset in the ARM Archive. Reviewer 1 from the Quick Reviews of the manuscript suggested that Liebe91 was inaccurate and suggested several other cloud liquid water models. Since D. Turner is a co-author of the TKC15 study, which is particularly well suited to supercooled water studies, and had a model ready to try in our framework, it was logical to use the TKC15 cloud liquid water model with a 3-channel LWP/PWV retrieval (23, 31, and 90 GHz).

The TKC15 paper goes into detail with comparisons to many other cloud liquid water models, including the Rosenkranz 2015 model. Please see Figures 5 and 6 in TKC15 for specific cloud liquid water model comparisons: reference – doi:10.1175/JTECH-D-15-0074.1. We believe that these figures in TKC15 address your question with regard to comparison of the current cloud liquid water models. The comment about the "improved convergence" of the retrievals in this manuscript was specific to using the TKC15 versus Liebe91 cloud liquid water model. We have added clarification that in our study the improvement is only referring to the use of TKC15 over the Liebe91 as it is relevant since the currently published retrievals still use Liebe91.

M2) We clarified the comparison of Liebe91 and TKC15 in Section 2.1.2 (see Page 6, lines 23 – 26 and Page 19, lines 10 – 14).

C3) Lastly, the authors excluded cases with LWP greater than 40 g/m2 to minimize the influence by liquid water. Since the radiative transfer simulation includes liquid water clouds, why does this constraint have to be placed? Is it because the MWRRET retrievals are completely unreliable for those cases even with the correction proposed in this study? For precipitation studies, those excluded cases may be more important. The reviewer is wondering whether observed radiometric signatures for those high-LWP cases can be used for physical retrievals.

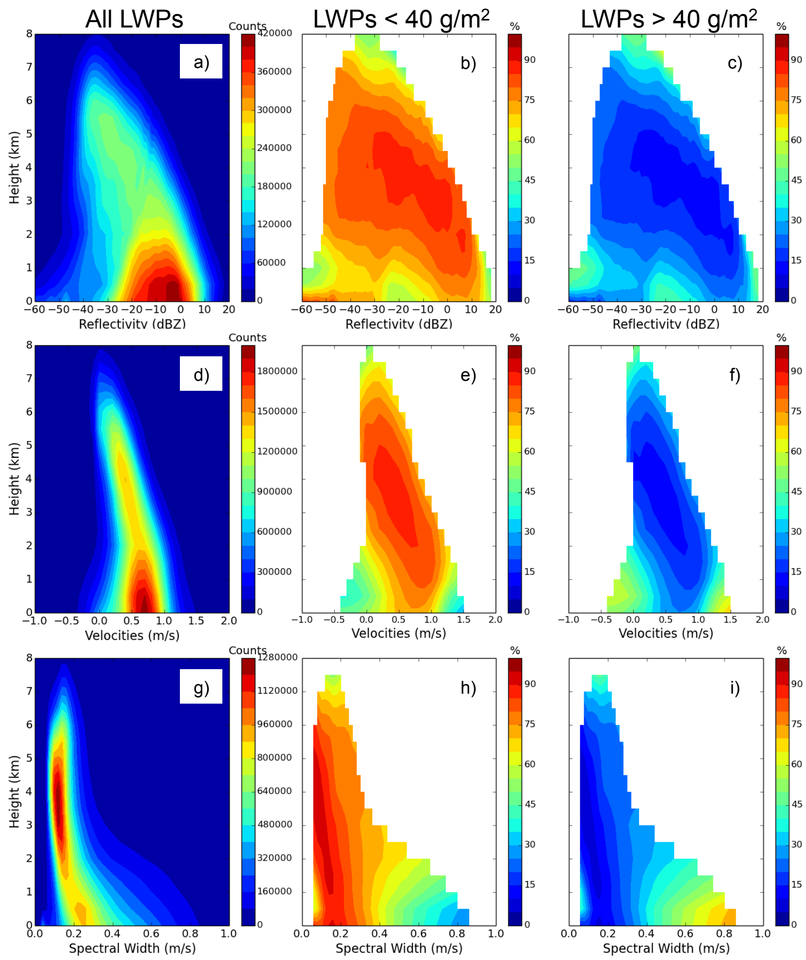
R3) The LWP constraint did not have to be placed, but it limits the analysis to cases where the separation of the ice and the cloud liquid water is simplified. Figure 1 shows CFADs of MMCR radar products for all cases and less and greater than 40 g/m^2. In Figure 1b (less than 40g/m^2) the reflectivity exhibits common ice hydrometeor characteristics and accounts for the majority of the cloudy cases for JJA at Summit. We inferred from these characteristics that we would still be examining a majority of the deep, ice cloud cases by limiting the LWP and aid in isolating the ice signature in the microwave. To better illustrate this point, we changed Figure 1 to show the percentage of the occurrence for the less than and greater than $40 g/m^2$ cases (see new Figure 1 at the end of this document).

This paper explores the first iteration of a process we hope to help separate out the ice from the cloud liquid water signal and going forward we will attempt to recover concurrent high LWP with high Z_{PATH} cases. In addition, with higher LWP, the optical thicknesses are less likely to be in the 'low optical depth' regime, which makes the passive microwave signatures more sensitive to details about the vertical distribution of the hydrometeors. Through this work we realized that the high Z_{PATH} and high LWP radiometric signals in the MWRs are difficult to disentangle and therefore we kept the $40 g/m^2$ threshold.

One note: we believe that the MWRRET LWP retrievals do a good job with greater than $40 g/m^2$ cases as long as the ice in the column has a low or moderate Z_{PATH} (i.e., less than $\sim 10^4$ mm^6/m^2). These high Z_{PATH} cases account for only 2% of the JJA data and thus the majority of high LWP retrieved by the MWR are likely accurate. However, if one examines only precipitating (snowing, high Z_{PATH}) cases at Summit, then the retrieved LWP values be affected by the radiometric signal by the ice in the column, regardless of the actual physical amount of LWP.

M3) New Figure 1, panels b, c, e, f, h, and i. (See Page 26). Explanation of Figure 1 revised in Section 3.1 (Page 9, line 26 – Page 10, line 14).

New Figure 1 –illustrates the different characteristics of MMCR properties when the LWPs are less than and greater than 40g/m^2 in terms of percentage of total counts:



Note to the Editor: After considering Comment 3 from Reviewer 2, we decided to recreate panels b, c, e, f, h, and i of Figure 1 in terms of percentage of LWP filtered observations by total observations. We believe that this illustrates the characteristics of the hydrometeors as related to the LWP more clearly.