Reply to referee#1

We would like to thank the referee #1 for the constructive comments, which helped to improve the manuscript. We have considered all the recommendations. In the following reply we repeat the statements of the referee (in red) and the reply to each statement of the referee (in black). Note that in the statements of the referee the line and figure numbers refer to the original manuscript and may have changed in the revised version. In the replies the line and figure numbers correspond to the revised version.

P1,L16: clouds do not conserve LW radiation; "emit" is a better word here

- ✓ Corrected

P2,L3: midsummer SW radiative cooling of the surface is not a general feature across the Arctic. You might indicate that clouds cool the surface the entire year at a site like Summit Greenland (Miller et al. 2018)

- ✓ We added the following sentence (please, see the page 2, line 5):
  "This summer SW radiative cooling of the surface was reported for different Arctic regions except the Summit station in Greenland where the cloud radiative forcing effect is positive the entire year due to high surface albedo of the snow coverage (Miller et al. 2015, Miller et al. 2017)."

P2,L33: sensors cannot "capture low level clouds" –"observe" is a better word

- ✓ Corrected, (please, see the page 3, line 1).

P4,L29: "multi-variable"

- ✓ Corrected, (please, see the page 5, line 3).

P6,L27: I am not sure what these double values (e.g., "+100% / -30%") mean here. Please clarify

- ✓ The uncertainty here are given with respect to the reference IWC (from in-situ), i.e. for the ratio between retrieved and measured IWC. For instance, "+100% / -50%" means that the retrieved IWC is a factor of two larger or smaller than the measured IWC, respectively. The numbers here were taken from Hogan et al. (2006).
- ✓ There was a typo in the text regarding the uncertainty values. The numbers "+100% / -30%" were corrected to the right ones "+100% / -50%".
- ✓ Unfortunately, Hogan et al. (2006) do not provide numerical values for the temperature range from -40° to -20°C and it is hard to estimate the precise numbers from the figure they give. Therefore, we also check the uncertainties of the method in Heymsfield et al. 2007.
- ✓ We added the following sentence: "Hogan et al. 2006 found that uncertainties of the IWC retrieval differ for different temperature ranges and are estimated to be from -50% to +100% for temperatures below -40°C and ranging from -33% to +50% for temperatures above -20°C. The numbers here are root mean squared errors given with respect to the reference IWC. Evaluating the method of Hogan et al. 2006, Heymsfield et al. 2007 found similar uncertainties, except that there was a positive bias of about 50 % for temperatures above -30°C. The authors estimated the uncertainties from 0% to +100% and from -50% to +100% at temperatures above and below -30°C, respectively." (please, see the page 7, lines 12-17).

P7,L3: "US NationalWeather Service's"

- ✓ Corrected (please, see the page 7, line 27).

P10,L6: I found this minimum in July surprising. I suspect this is just a sampling error due to a relatively small dataset. I would encourage the authors to bring out this point more strongly here and in the conclusions of the paper

- ✓ The Cloudnet algorithm requires both radar and ceilometer measurements to be present, with the ceilometer able to distinguish cloud from warm precipitation. The ceilometer was out of operation for a few days in both July 2016 and July 2017, hence the reduction in Cloudnet data availability. We manually calculated the cloud fraction using only the radar measurements, and the cloud fraction results did not change much. Based on radar-only observations, which give a data availability of 99 %, we found the total cloud fraction to be around 80 %, with 19 % clear sky cases, very close to the Cloudnet (lidar and radar) calculations.

P11,L20-25: Shupe et al. 2015 also had the same challenges in distributing liquid water vertically in mixed-phase clouds. Does the CloudNet algorithm use the same scaled-adiabatic method? Perhaps mention both the Shupe paper and address this question here.

- ✓ Cloudnet also uses the scaled-adiabatic method for distributing liquid water vertically in liquid clouds (including liquid layers in mixed-phase clouds), using cloud boundaries from radar and lidar together with LWP from HATPRO. We added the reference to Shupe et al., (2015) which acknowledges the challenges of using this method in multi-layer situations. Please, note that in the paper we neither analyze LWC profiles nor focus on the detection of multiple liquid layers in mixed-phased clouds. We also do not try to classify multi-layer clouds into any further classes (like ice-ice, mixed-ice). In this paragraph we just explain why we do not take multi-layer cloud for further analysis. We describe the observational capabilities and limitations for liquid and mixed-phase multi-layer clouds.
- ✓ We modified the sentence (please, see the page 12, lines 13-15): "In situations with multiple liquid layers, whether warm or mixed-phase, partitioning the observed LWP from HATPRO among these different layers is particularly challenging and results in larger uncertainties (Shupe et al., 2015).".

P13,L1: There were not 26 NWP models in the Klein et al. study. Most were very experimental cloud-resolving or LES models.

- ✓ We removed the word "NWP" (please, see the page 13, line 33).

P14,L7: "represented" is a better word than "reprocessed"

- ✓ Corrected, (please, see the page 15, line 9).

P14,L10: What sort of radar reflectivity does this represent, given typical hydrometeor sizes? Perhaps a statement can be made here about the advantage of using an instrument simulator?

- ✓ We added the following sentence (please, see the page 15, lines 16-22): "According to the Z-IWC-T relation from Hogan et al (2006), the chosen threshold in the ice mixing ratio corresponds to the radar reflectivity factor ranging from -55 to -32 dBZ at temperatures from -60 °C to -5 °C. In general, these values are close to the radar sensitivity, although at high altitudes the radar sensitivity is about -40 dBZ (Küchler et al. 2017). Nevertheless, most of the observed hydrometeors are located within 2 km from the surface (see section 4.1) and, therefore, the lack of sensitivity at high altitudes does not significantly affect the results. For more detailed analysis of the uncertainties due to differences between the instrument and the model sensitivity can be done using observation simulators (e.g. Haynes et al. 2007). Such the analysis is out of the scope of the current study."

P14,L23: you state ": : :these ice-related processes are longer in the real cloud than it is specified in ICON model." Does this mean that you believe that the model has the processes act more rapidly than they do in nature? This sentence needs clarification

- ✓ As we show the highest occurrence of single-layer ice clouds in the ICON model is at relative humidity over ice of up to 110 %. Real clouds are observed at higher ice supersaturation

conditions (125 %). This might be associated with a different number concentration of ice particles or/and depositional growth efficiency. For instance, if the number concentration of ice particles parameterized in the ICON model is higher than the real one, the water vapour deposits faster onto the ice particles due to larger total surface area of particles and the conditions of higher supersaturation (125 %) might be not reached. The number of formed particles depends on the nucleation processes. Therefore, the difference in the concentration might come from the parameterization of ice nuclei in the ICON model.

- ✓ The sentences were modified (please, see the page 15, lines 29-32, page 16, lines 1-2): "The presence of ice particles at lower supersaturation over ice in the ICON model in comparison with observations may be associated with ice nuclei (IN) parameterization in the ICON model, which is known to be still a challenge (Fu et al., 2017). We speculate that a higher concentration of IN and, thus ice particles, leads to faster deposition of water vapour onto the ice particle's surface. Therefore, a more efficient vapour-to-ice transition in the model could lead to lower relative humidity. Similarly, the parameterization of deposition growth rate and secondary ice processes may also have an impact on the in-cloud relative humidity."

P15,L19: "categorization"→"classification"

- ✓ Corrected, (please, see the page 16, line 30).

P16,L33:These clouds with LWP values between 30 and 60 g/m2 also have the largest radiative contribution to the surface energy budget (Bennartz et al. 2013)

- ✓ Added, (please, see the page 18, lines 11-12).

P18,L3: The L&C paper only talk about higher frequency microwave radiometer measurements. If you want to include the IR here (and you should), then please reference either Marke et al. 2016 or Turner 2007

- ✓ Corrected. Both references were included, (please, see the page 19, lines 12-13).

P18,L6: how would the effective radius be determined?

- ✓ Modified, (please, see the page 19, lines 16-17): "The next step will be to derive cloud microphysical properties such as LWC, IWC and effective radius for different types of clouds using methods by Frisch et al. 1998, Frisch et al. 2002, Hogan et al. 2006, Delanoe et al. 2007."

Fig 9, panels B and C: the most important clouds from a radiative point of view are the ones with smaller LWP and IWP. However, the linear x-axis sort of hides them. Would you consider plotting these data on a log10 axis from 1 g/m2 to 1000 g/m2 for LWP? The bins should be equal-sized bins in log10(LWP) space. Ditto for the IWP, but perhaps start the lower range at 0.1 g/m2?

- ✓ Please find the plot below this answer. As mentioned in the section 2.2 the uncertainty of the LWP retrieval based on the MWR observations is 20-25 g/m^2. Thus, we do not see a need to subdivide the first bin into smaller ones. We also think that it could be a bit confusing for a reader to look at the logarithmic distributions of LWP and IWP. The bins have significantly different width in the linear domain and cannot be compared with each other. This also lead to significant changes of the distribution peaks which may be misleading.

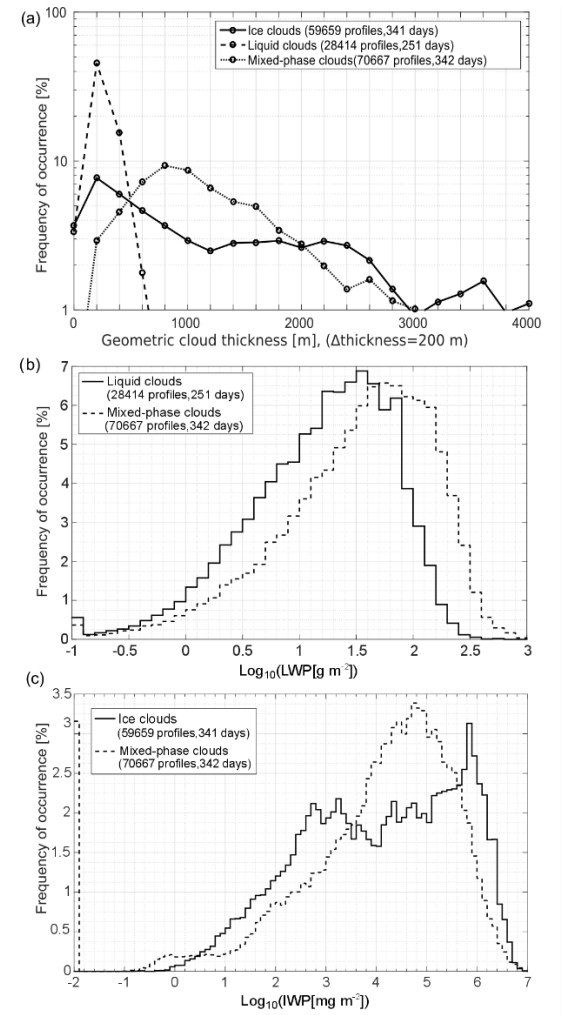

Fig11: I don't see the labels for the individual panels (e.g., "a", "b", etc). Also, there seems to be some weird inset artifact on the lower left-hand panel.

- ✓ Corrected, (please, see the Fig.13).
- ✓ The font size of labels was changed.

Fig12: I would emphasize that the ICON results are not "global", but are from output over the Ny Alesund

- ✓ Corrected, (please, see the captions to the Fig.13 and Fig.14).