Response to Dr. Devasthale

We thank you, for your time and efforts in giving valuable comments.

Before we address the points you raised, we would like to point out an error that we have already corrected in the manuscript: The CTH comparison period is for NSA and Summit from 2012-2016 and 2010-2014, respectively. Apologies for the inconvenience.

The remarks by the referee are in red, our answer is in black.

Q1) Not including time component seems to be a missed opportunity. Why not show a few evaluation metrics as a function of time, esp for those stations where the longer measurements are available? Given that the meteorological and thermodynamical conditions (and thus their impact on cloud properties) do vary significantly among the sunlit months in the Arctic, it would be really useful to the users to understand the performance of ESA-CCI-Cloud products during the various sunlit months.

Q2) Another aspect related to the point above would be to express bias or metrics as a function of solar zenith angle and/or viewing zenith angle.

The following answers correspond to both Q1 and Q2

A1) As part of the preparation of the manuscript, we also looked at time series. Although it is a 9-year period (2010-19) over NSA, a large number of samples are not suitable for direct comparison with ground-based instruments because the cost functions of the satellite observations are too high. This is a fairly expected scenario for most passive satellite sensors over the Arctic. However, the main problem is that the days that are eligible for validation are not the same over the entire period. This condition has prevented us from directly comparing the time series or trend assessment. E.g., in 2010 we obtained the samples for the first days of April when the melt starts and the clouds are visually dense, but in the following year, 2011, the samples may have been selected somewhat after this regular Arctic activity, which may not representative as in 2010.
However, below are the plots, Fig. 1-3, in which temporal comparisons were made between the satellite and ground-based instruments for the sites for which long-term data are available. From the results, it can be seen that the slopes of the annual variations have the same sign for both satellite and ground-based instruments. The increase in LWP from 2015-2017 over NSA is very well captured. In most cases (> 95%), the CCI median values are within 50% of the ground-based distributions. A CTH decline of about 100 m/yr observed in the ARM NSA is consistent with the CCI. The observed slope values of ground-based COD (and COD equivalent), which are ~0.6 units/year, are also consistent with satellite observations (note that these are not statistically significant though).

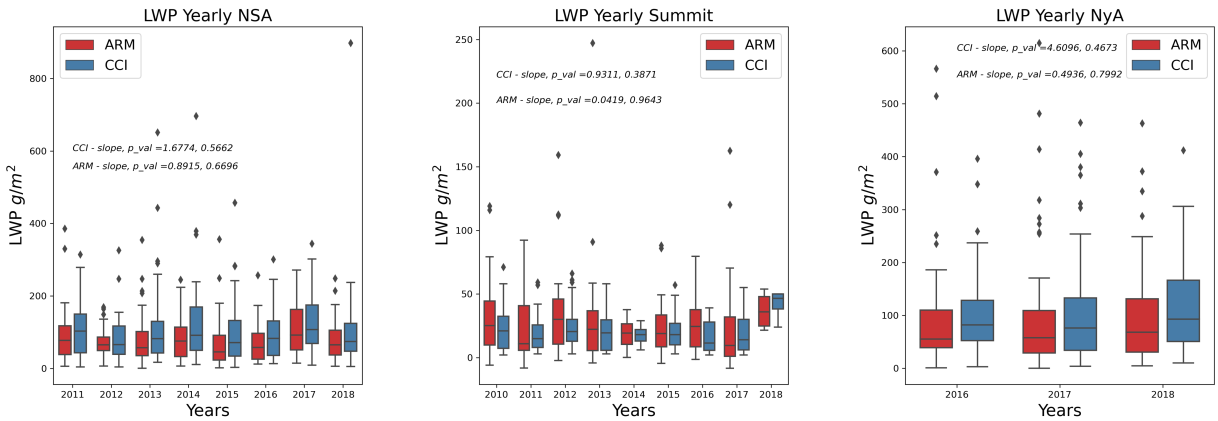

Fig 1: Temporal variations of LWP over NSA, Summit and Ny-Ålesund (NyA)

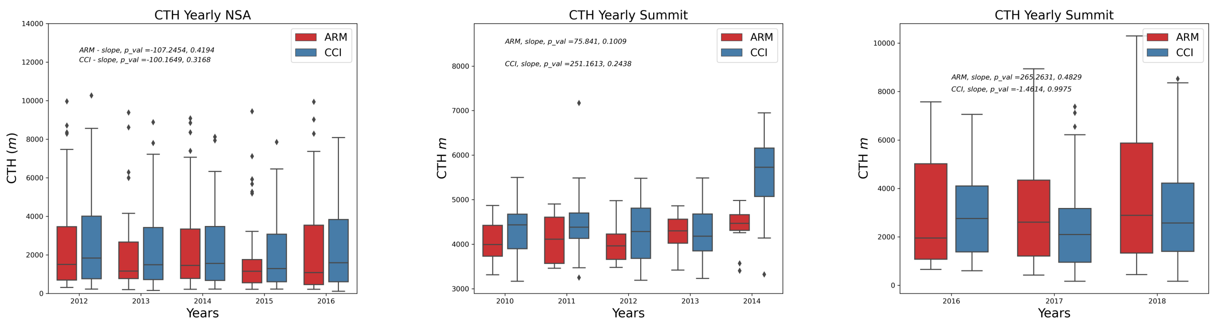

Fig 2: Temporal variations of CTH over NSA, Summit and Ny-Ålesund (NyA)

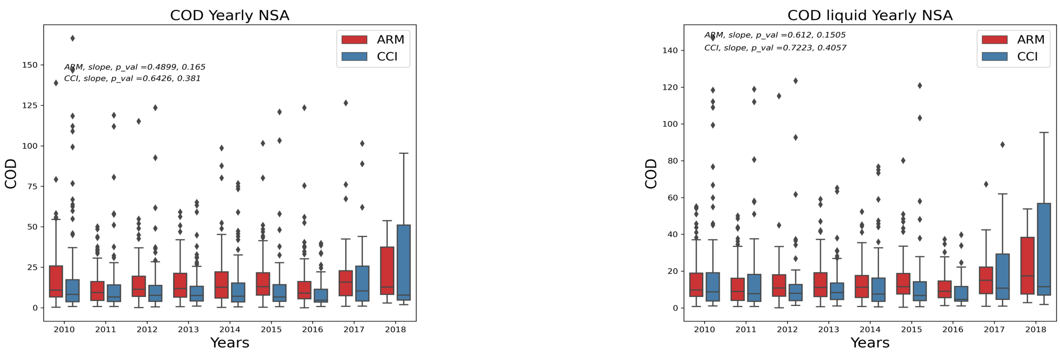

Fig 3: Temporal variations of COD (all cases) and COD (only liquid clouds) over NSA

A2) SZA/VZA: The separation based on SZA does not provide thresholds that justify good/bad results. One of the main reasons could be using a “best pixel” with the lowest SZA in the L3U grid products.

Q3) Near-isothermal conditions in the lower boundary layer and temperature inversions make it notoriously difficult to place clouds at the right height in the passive retrievals. Is this also the case for CCI-Clouds retrievals? If so, there is not much discussion or investigation of this aspect in the CTH evaluation.

A3) Undoubtedly, the mentioned aspects lead to the complication of the situation. Exactly these aspects have led us to this validation study. We wanted to know how good the quality of the cloud products of the dataset is under Arctic conditions, although it is actually a global retrieval.
In terms of cloud top, we were surprised by how well the results agreed. From our point of view, the situation for the CTH over Summit is not directly related to the general Arctic conditions, but rather to the special ones over Greenland: optical, relatively thin clouds which have a rather low cloud top (Bennartz et al., 2013) and is potentially affected by temperature inversions at the very surface (~2m) and higher above (Adolph et al., 2018).

Q4) What role does the AVHRR detection sensitivity actually play when you stratify the results in Fig. 2 according to COD? The results presented in Fig. 12 in Karlsson and Håkansson (2018) are relevant here and should be discussed.

A4) Thanks for the valuable suggestion, it is indeed relevant and needs to be discussed. From Fig. 12, 13 in Karlsson and Håkansson (2018), the minimum optical thickness required for cloud detection ranges from ~ 0.5 to ~ 4.5 depending on the region. In our case, which is over Alaska, it almost meets the threshold values. A new line is added in the current version 261-264.

Q5) Are there more data available from the ground-based measurements taken in the ACTRIS framework in the Arctic? If so, they would also be useful here.

A5) Thank you for the recommendation, ACTRIS is useful. But the cloud parameters that are relevant to us, cover similar stations that we have targeted.

Q6) Were there mixed-phase clouds detected in the ground-based retrievals? If so, how are those samples handled?

A6) This study does not address mixed-phase clouds in either satellite or ground-based measurements. We are aware that this limits our study to some degree. However, this limitation applies to most cloud research in the Arctic and is a general problem due to the lack of coverage of measurement data.

References:

Adolph, A. C., Albert, M. R., and Hall, D. K.: Near-surface temperature inversion during summer at Summit, Greenland, and its relation to MODIS-derived surface temperatures, The Cryosphere, 12, 907–920, https://doi.org/10.5194/tc-12-907-2018, 2018.

Karlsson, K.-G. and Håkansson, N.: Characterization of AVHRR global cloud detection sensitivity based on CALIPSO-CALIOP cloud optical thickness information: demonstration of results based on the CM SAF CLARA-A2 climate data record, Atmos. Meas. Tech., 11, 633–649, https://doi.org/10.5194/amt-11-633-2018, 2018.

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