RC 2 answer:

Comments:

The authors present ground-based lidar observations of cold clouds in Andenes (Norway), covering a period of seven years. They explored two case studies to assess 1) the agreement between a co-located cirrus observation from ground-based lidar and CALIPSO, and 2) the ground-based lidar's capability of determining cloud phase in mixed-phase clouds from depolarization measurements. Also, they presented statistics of cold clouds macrophysical properties for the period 2011-2017.

I find the manuscript interesting and well-organized. I have the following comments that require clarifications before publication of the manuscript.

> We want to thank Reviewer 2 for the helpful comments, which definitely helped to improve our manuscript. Please find our point-by-point responses to your comments below. When citing the text from the revised manuscript in the responses, we refer to page and line numbers in the new manuscript. If only single words are changed in sentences, they are given in italic font.

Clarification needed:

- The authors mentioned that they used 137 ERA5 pressure levels. What is known is that ERA5 are available at 137 model levels (not pressure level) and 37 pressure levels (coarse). Please clarify if some conversion procedures have been used or correction is needed?
    - Thanks for pointing out this inconsistency. We used 37 pressure levels. The 137 model levels are not relevant for the article and the number should not be mentioned. The number of pressure levels in the article is changed to 37 (see page 5, line 149-150).
- Based on Figure 1, in average ERA5 can overestimates (underestimates) cloud top temperature with a difference that can reach ~10 K. Please, elaborate on the effect of these differences on your results and conclusion, especially for the period before 2014?
    - Thanks for the comment. Considering the uncertainties, we admit that the bin width of 1 K in Fig. 7a+b of the submitted version suggests a higher accuracy than there actually is. Therefore, we decided to increase the bin size to 2.5 K, thus enabling us to draw conclusions about the general CTT distribution of cold clouds without a large bias introduced by the choice of the reanalysis product. We chose 2.5 K based on previous estimates of the validity of atmospheric reanalysis temperatures in the Arctic: Jakobson et al. (2012) found a bias of up to 2°C for the lowest 890 m when comparing tethersonde data from an Arctic drifting ice station with ERA-Interim reanalysis data. Graham et al. (2019) compared ERA5 reanalysis data with radiosondes launched from two ship campaigns in the Fram Strait and found a vertically averaged absolute bias of 0.3°C. Other reanalysis products in their study also showed biases of less than 0.6°C. In addition, our own comparison of the radiosonde data from Andenes with ERA5 data yielded a bias of 1°C (see manuscript). This gives us confidence in the use of different reanalysis products for the spaceborne and ground-based retrievals of the CTT.

Jakobson, E., Vihma, T., Palo, T., Jakobson, L., Keernik, H., and Jaagus, J. (2012), Validation of atmospheric reanalyses over the central Arctic Ocean, *Geophys. Res. Lett.*, 39, L10802, doi:10.1029/2012GL051591.

Graham, R. M., Hudson, S. R., & Maturilli, M. (2019). Improved performance of ERA5 in Arctic gateway relative to four global atmospheric reanalyses. *Geophysical Research Letters*, 46, 6138– 6147. https://doi.org/10.1029/2019GL082781

We included the following discussion regarding temperature reanalysis products (page 6, line 168 – page 7, line 179):

"We are aware that the use of different reanalysis products for temperature retrievals introduces uncertainties. However, since ECMWF-AUX has been specifically designed to provide profiles of temperature from atmospheric reanalysis interpolated on the time and location of the CloudSat/CALIPSO overpass, this makes it the first choice to use in combination with the phase retrieval from the 2B-CLDCLASS-LIDAR product. To draw conclusions about the general CTT distribution of cold clouds without a large bias introduced by the choice of the reanalysis product, we pick a bin size of 2.5 K when showing the distributions in Fig. 7. The choice of 2.5 K is based on previous estimates of the validity of atmospheric reanalysis temperatures in the Arctic: Jakobson et al. (2012) found a bias of up to 2 K for the lowest 890 m when comparing tethersonde data from an Arctic drifting ice station with ERA-Interim reanalysis data. Graham et al. (2019) compared ERA5 reanalysis data with radiosondes launched from two ship campaigns in the Fram Strait and found a vertically averaged absolute bias of 0.3 K. Other reanalysis products in their study also showed biases of less than 0.6 K. In addition, our own comparison of the radiosonde data from Andenes with ERA5 data yielded a bias of 1 K. This gives us confidence in the use of different reanalysis products for the spaceborne and ground-based retrievals of the CTT."

- In addition to the spatial difference, what is the average time lag between the radiosonde and ERA5 (for cloud top temperature)?
    - The ERA5 temperature is from the closest full hour to the measurement time. The radiosonde is only released twice a day. The average time lag between both temperature retrievals is 3 hours and 20 minutes. This is now added to the manuscript (page 5, line 150-151):

      "Additionally, the average time lag between the retrieved ERA5 temperature (available at full hours) and the radiosonde release (twice a day) in Fig. 1 is 3 hours and 20 minutes."

- Also, the vertical resolution of ERA5 at pressure levels is still coarse (not the case for model level, especially at the cirrus cloud levels). Using the interpolation can omit some important details, especially for thin cirrus. Please elaborate?

- That's right, the resolution of ERA5 pressure levels is still coarse. We added the following sentence in addition to the clarifications regarding temperature reanalysis stated above (page 5, line 145-146):

  "The rather coarse vertical resolution of the ERA5 reanalysis might omit details in the thermal structure around cirrus clouds."

- Line195: Which method is used to estimate the tropopause? Please clarify?
  - Thanks for pointing out this missing information. We apply the lapse rate definition from the World Meteorological Organization, stating that the tropopause starts where the temperature decrease with height stops. This is added in the manuscript (page 9, line 216-218):

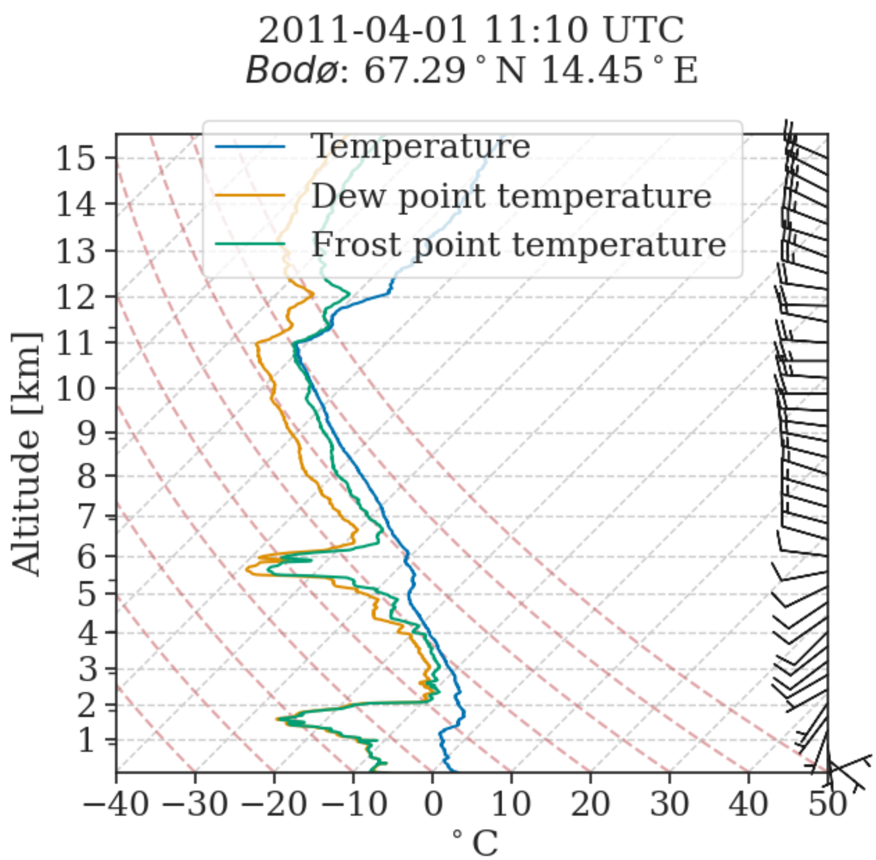
    "*Applying the lapse rate definition of the tropopause by the World Meteorological Organization (WMO)* we estimate the *beginning of the* tropopause to be located at about 11.0 km (from radiosonde) or 10.6 km (from reanalysis data) *and* at a temperature of -70 °C."

- Please clarify further about phase discrimination between cirrus, mixed-phase and liquid clouds, during maintenance break from April 2013 to July 2015?
  - We did not include the time period April 2013 to July 2015 for the ground-based observations, as the maintenance break made measurements impossible. Thus, also no phase discrimination has been applied for this period. The phase discrimination for the 2B-CLDCLASS-LIDAR product is explained in Sassen et al. (2008) and referenced in Sect. 2.2. (No change in the manuscript.)

- The authors mentioned that ".... Thus, the cirrus cloud is extending well into the tropopause, dehumidifying the upper troposphere and lower stratosphere region through ice crystal growth and sedimentation."

- Can you provide evidence (quantification) on dehumidifying the lower stratosphere caused by cirrus? Also, on cirrus reaching lower stratosphere causing dehydration.

- I would like to see figures and discussion about the corresponding relative humidity with respect to ice (in-cloud and clear-sky) associated with cirrus cloud. Also, its impact on cirrus cloud, dehydration, and your conclusion.
  - For this specific case, from elastic lidar data only, we can't quantify the amount of dehydration. But we can see that the relative humidity with respect to ice is significantly larger than 100% inside the cloud and until 11.7km, which corresponds roughly to the cloud top and is above the beginning of the tropopause. For the sake of clarity in presentation we did not add an extra figure showing the relative humidity with respect to ice, but for demonstration we added the frost point temperature to the following sounding plot.



There we can see that the decrease in frost point temperature and thereby humidity first begins well above the altitude where the temperature decrease stops. Therefore we can conclude that the cirrus cloud removes vapor from the tropopause by forming ice crystals that then fall and evaporate in the troposphere. But again, quantitative studies of dehydration are not possible with this setup and beyond the scope of the study. The case is meant as a qualitative example.

To make limitations clearer, we added the word "potentially" before "dehumidifying" in the manuscript and added one extra sentence. The new text is (page 9, line 218-221):

"Thus, the cirrus cloud is extending well into the tropopause, *potentially* dehumidifying the upper troposphere and lower stratosphere region through ice crystal growth and sedimentation (e.g., Kärcher, 2005). *However, a quantification of dehydration in this case requires knowledge of further cloud parameters and is beyond the scope of this study."*

Minor comments:

Correct "occurence" --> occurrence. (lines 8, 22, 57, 64,66, 291 and y-axis of Fig.5b)

Thanks for pointing that out. It is now changed in both text and figures.