Interactive comment on “Classification of Arctic multilayer clouds using radiosoundings and radar data” by Maiken Vassel et al.

Anonymous Referee #1

Received and published: 28 September 2018

Review of “Classification of Arctic multilayer clouds using radiosoundings and radar data” by Vessel et al.

We thank the anonymous reviewer for his/her review and the detailed comments. We have revised the manuscript accordingly, including a revision of all sublimation calculations, updates of all figures, and major changes of the text. Our replies to your comments are given below in blue after the specific comment. Our page references refer to the corrected version of the paper.

Recommendation: Might be acceptable for publication after mandatory revision

This paper analyzes a year of data collected by a radar and radiosoundings at Ny-Alesund and attempts to determine the frequency of occurrence of multi-layer clouds, and in the case of multi-layer clouds whether the cloud layer underneath is seeded by the cloud above. The subject matter is timely because the Arctic is currently warming quicker than other parts of the planet, yet models have a difficult time accurately predicting the amount of warming. Better knowledge of the properties of arctic clouds, and on what controls them, is necessary in order to improve these predictions: any paper that hence contributes to our data base on the phases, heights and geometrical characteristics of clouds is beneficial. The paper is well written and the presented analysis easy to understand. Nevertheless, I fear that the paper as currently written is quite misleading. There are so many uncertainties and problems with the analysis (which, in their defense, the authors do a good job of identifying) that I fear the results that come out of the paper are not terribly useful. However, I think if the data were presented in an alternate way the study could be of potential use and hence I am recommending major revision rather than rejection.

Step 1 of their analysis uses the radiosonde data to identify the presence of multi-layer clouds. However, even though the probability of detection of the multi-layer clouds is 99% with this method, the false alarm rate of 58% “reveals that about half of the MLC detected by radiosounding is no MLC by radar.” Thus, it seems that the paper should be reworded to emphasize that the use of the radiosonde data on its own does not reliably identify the occurrence of MLCs, but can be used in combination with radar data to give information on the presence of MLCs. The authors acknowledge the unreliability of the radiosonde data on their own to identify MLCs as they state “even if the layers above and below are supersaturated with respect to ice, the lack of suitable IN can prevent ice cloud formation.” They also stated that “the results obtained by the radiosonde profiles disagree with actual MLC occurrence observed by the radar.”

It is true that we find using only radiosonde data not being the best method to detect cloud layers. The use of radar instead would lead to much more reliable statistics about visible multilayer clouds. For this we refer to Nomokonova et al. [2018]. However, our main idea was to investigate the possibility of seeding in connection with multilayer clouds. In order to do so, a radiosonde profile is essential to calculate the possibility of seeding (using the temperature and humidity profile of the radiosounding). Using primarily radar and in a second step the radiosonde does not solve the problem, since we show that seeding does hardly ever occur in between two in the radar visible cloud layers (cat. 8 in Fig. 8 in Vassel et al. [2018]). That means seeding itself can very poorly be differentiated from a cloud layer in the radar. Because of that we use primarily radiosonde data and radar data only as a further measure, even if this leads to high uncertainties. We have reworded some of the paragraphs in order to make clear that both radiosonde and radar is needed (p.10 l.16-17, p.15 l.16-17).

The second major problem with the analysis presented is the reliance on the chosen ice crystal size to calculate which of the upper layers of MLCs is seeding a lower layer. As stated by the authors "varying the initial ice crystal size has a large, non-linear impact on the distribution between seeding and non-seeding subsaturated layers." Further, their calculations substantially underestimate the variance that the size of the seeding ice crystal size might have. In several studies of in-situ measurements of mixed-phase clouds, the ice crystal sizes have been much larger than the 150 micrometer size assumed in the calculations here. Further, the calculations assume a hexagaonal plate which is not representative of the shapes of ice crystals in mixed-phase clouds. For example, Korolev et al. (1998) found that over 98% of ice crystals in mixed-phase arctic clouds had irregular shapes. Thus, the uncertainties will be much larger than those stated, and the stated uncertainties are already huge. And, the base size of 100 micrometers is probably much smaller than the size of particles that will be emanating from the upper layer.

This is a valid comment, and we have revised the calculations taking into account larger crystal sizes. The upper cloud of a MLC, from where the falling ice crystals origin, can either be a mixed-phase cloud or a cirrus cloud. In mixed-phase clouds Korolev et al. [1999] measured ice crystals with radii of about $r$ =400 $\mu$m. We also refer to Fig. 5e in Mioche et al. [2016], where a radius of $r$ =400 - 500 $\mu$m can occur in mixed-phase clouds. For cirrus clouds Krämer et al. [2009] showed that the radii of ice crystals range between $r$ =1 - 100 $\mu$m. In order to account for both cloud types, we have redone our calculations for the ice crystal sizes $r$ =100, 200 and 400 $\mu$m. Our main focus is now on $r$ =400 $\mu$m, assuming in most cases the upper cloud to be mixed-phase.

We agree with you that the ice crystal shape should not be treated as a sphere. We changed the calculation and the text accordingly (p.4 and p.6). We have selected the four ice crystal shapes hexagonal plate, rimed particle, stellar and irregular particle which are representative for mixed-phase clouds [Mioche et al., 2016]. For these particles we use the fall speed calculation shown in Fig. 1 and given by Mitchell [1996]. The main focus in the paper is on the hexagonal plate. The results for the other shapes is presented in the Appendix. We do not account for the lower limit of ice crystal size given by Mitchell [1996], since in our calculation we have to calculate the speed also for very small ice crystals due to sublimation. Note that this might lead to a small error of too fast falling small ice crystals.

We also corrected the capacitance. We are now using the calculation of Westbrook et al. [2008]. The cases selected are listed in A1 of the paper, as well as the aspect ratios chosen by us.

In Fig. 2 we present the variation of the different ice crystal shapes on the result of classification step 2. As mentioned in the paper, on classification step 1 there is a small variation, but on classification step 2 there is almost no impact of the ice crystal shape on the result (p.10, l.4 and p.12, l.14-15).

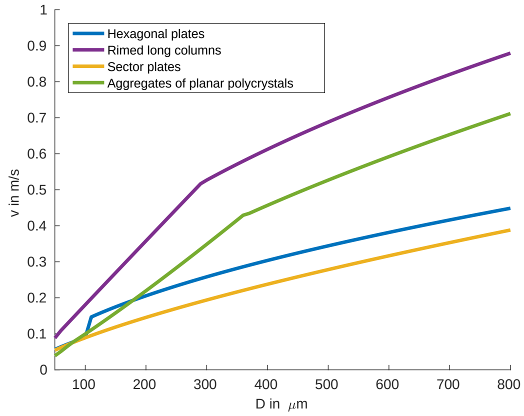


Figure 1: Ice crystal fall speed in dependence of particle size [Mitchell, 1996]

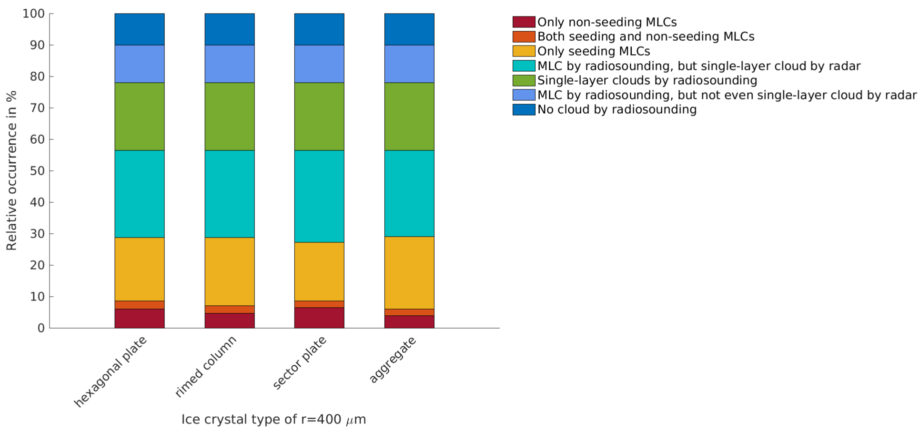


Figure 2: Classification step 2 using different ice crystal shapes with $r = 400\ \mu$m.

Another potential problem could be the lack of colocation between the radiosondes (which can drift large distances in the background wind) and the radar, which is again noted by the authors: “horizontal drift of the radiosonde away from the radar and inaccuracies due to time averaging of the radar data can explain contradictions between radiosounding and radar." Was any effort made to consider the advection of air parcels measured by the radiosondes so that the radar data at an appropriate time could be used in the analysis (provided that the air parcel was within the radar view volume at some time)?

In response to this comment, we have revised our calculations. In order to account for the advection, we calculate the wind speed in each layer. Using this information together with the distance between the radiosonde and the radar, we calculate the time the air parcel needs to drift from the radar to the position of the radiosonde. For this we do not consider the wind direction, but assume that the air parcel drifts the same direction as the radiosonde. As an example we show the results of the calculation for 3 November 2016 (Fig. 3). For the 3 November 2016 the average time over all heights is 12.94 min. For our statistics we have added the average time for each day to the time chosen for the evaluation of the radar data. For the 3 November 2016 the resulting radar time period is shown in Fig. 4. The results were changed only marginally by this correction.

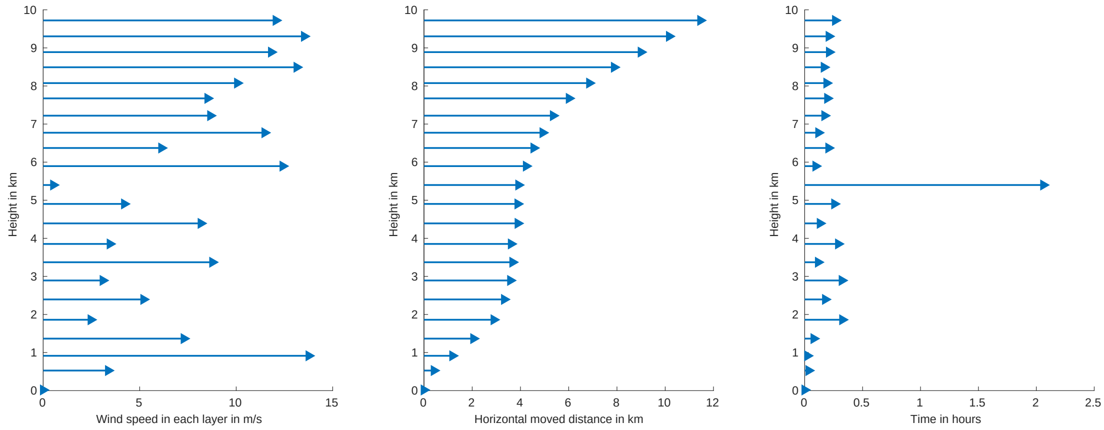


Figure 3: Advection on 3 November 2016: a) windspeed in each height layer, b) estimated distance between radar and radiosonde, c) estimated time that the air parcel needs to drift from the radar to the position of the radiosonde.

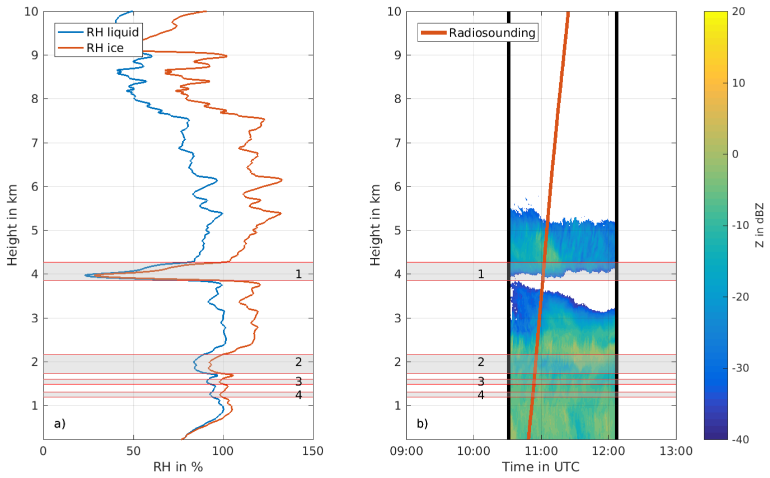


Figure 4: a) Radiosonde data, b) radar time period corrected due to advection

MORE DETAILED COMMENTS:

Abstract: At first reading, I was confused that the 9% and 23% of the cases mentioned because it did not add to 100%. Perhaps mention that other cases (of the 8 categories) are included to avoid confusion.
Thanks for this comment, we added the following bracket to make it clearer: "Seeding cases are found often, in 23 % of the investigated days (100 % includes all days, also non-cloudy days)".

Page 1, Line 24: I find trying to differentiate between the terms multilayered clouds and multilayer clouds (MLC) very confusing! To me, that is the exact same word.
We agree with you that the use of the terms multilayered cloud/multilayer clouds create some confusion at the moment and are not used in a consistent way in literature. Verlinde et al. [2007, 2013] describe a multilayered cloud as a continuous cloud layer with a variable lidar signal inside this cloud layer. It refers to one cloud with different layers. We use the word multilayer clouds referring to separate clouds with clear visible interstice in between. In our case we refer to cloud layers in the atmospheric column, not layers within the cloud.

Page 3, line 6: Do you expect any diurnal cycle in the cloud properties that would mean that the derived statistics are not representative of the Arctic as a whole?
We did not investigate the diurnal cycle in the cloud properties. This is not possible since the radiosonde is most of the year only launched once per day (11 UTC). Since we do not expect any diurnal cycle, we consider the statistics as representative for the location as a whole. However we want to point out that there are differences in the weather at Ny-Ålesund compared to other locations in the Arctic due to the location in a fjord on the west coast of Svalbard compared to the typical sea ice influenced high Arctic. We consider Ny-Ålesund as an Arctic but not as a high Arctic location.

Page 3, line 10: I think data is plural, so it should be “data are” rather than “data is”
We have changed it at page 3, line 10. At other places either only radiosonde or only radar is used in connection with data. Then it is grammatically correct to use “radar data is”.

Page 3, line 28: What statistical test was applied to show that the results did not change significantly?
No statistical test was applied. The use of the word significantly is wrong here. It is now changed to substantially.

Page 7, line 9: Why is only the lowermost 100 m considered?
We rephrased the sentence to make this more clear to ”For the subsaturated layer in between only the lowermost 100 m are evaluated in order to address the question if the ice crystal survives so far. If the layer is thinner than 100 m only the available vertical thickness is considered.” If there is no radar signal in this lowest part, then the ice crystal has not survived.

Page 10, line 11: Vali (200x?) has recommended that ice nucleating particles (INPs) rather than ice nuclei (IN) be used in order to standardize terminology. Recommend that you use INP rather than IN.
Thanks for the comment, we have changed it accordingly.

Page 15, line 1: The cloud layers can slope up and down frequently (in relatively short distances or times) and that can have a big impact on averaging. Was this taken into account?
The radar signal was averaged over a time of $\pm$ 30 min. Sometimes we have conditions like e.g. no cloud/high cloud at the start time (-30 min) and later (+30 min) a cloud reaching much lower (e.g. 3.7., 31.7., 18.8., 2.10., 14.2., 21.5.). In these cases the layer is almost half covered and half not covered and it is unclear if this should be counted as a cloud containing layer or not. Then averaging is the most consistent solution. Reducing the average time to $\pm$ 15 min does not improve the results, the Heidke skill scores are reduced in this case by 0.02 and 0.01.

Page 17, line 3: Perhaps I am not looking in the right place, but I cannot find the supplement being referred to in this statement.
You are completely right. This is now corrected.

## References

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