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

Anonymous Referee #2

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Review of acp-2018-774 ——————————

Summary of the manuscript

The study titled "Classification of Arctic multilayer clouds using radiosonde and radar data" by Maiken Vassel et al. describes an algorithm for the classification of multi-layer cloud occurrence for a one year dataset in Ny Alesund, Svalbard based on radiosonde and vertically-pointing cloud radar observations. The classification is two-fold: Firstly, only the conditions for cloud occurrence based on radiosonde humidity profiles consisting of two supersaturated layers separated by a subsaturated layer are analyzed. The fall distance of a hexagonal ice crystal of 100 micron size before complete evaporation in the subsaturated layer are estimated. The subsaturated layers are then classified into two categories. The first category is called "seeding", referring to layers with a

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Discussion paper

vertical extent lower than the fall distance before complete ice crystal sublimation. The second category is called “non-seeding”, referring to layers with a vertical extent higher than the fall distance before complete before complete ice crystal sublimation. These maximum possible occurrence frequencies for multi-layer cloud occurrence based on supersaturated layers as identified by radiosonde ascents are then verified by cloud radar reflectivity profiles obtained within 30min before radiosonde launch and 30min after the radiosonde has reached 10 km altitude. Multilayer mixed-phase cloud occurrence was found in 29% of the cases based on the combined radiosonde-cloud radar estimation. One of the main finding of the paper is that about 50% of the multilayer clouds estimated solely from radiosonde humidity profiles are not classified as such by the radar. - But the conclusion that radiosounding data is not sufficient for multi-layer cloud occurrence classification since not only humidity but also concentrations of ice nucleating particle (INP) and cloud condensation nuclei (CCN) are crucial is not made.

I would suggest the manuscript to be published after major revisions. The authors should address the following points:

Major comments ————————-

The literature review in the introduction should be extended. For example: p.1 line 20: Some more recent publications on Arctic mixed-phase cloud properties should also be included, for example Shupe 2011 (DOI: 10.1175/2010JAMC2468.1). In this paper. e.g., the occurrence of mixed-phase clouds at Arctic sites was found up to altitudes of 7-8 km.

p.2 line 18: Please give a broader and more detailed introduction on seeder-feeder mechanism and why it is important to consider it in the Arctic. Also, be more specific in which way the ice crystals falling from the upper cloud “influence” the lower cloud. Since this is a central question of this study, it has to be properly introduced.

The points made in various parts of the manuscript (especially Section 2.3) need to be more precise instead of using colloquial expressions like “surviving” ice crystals etc.

(e.g., also: p.6 line 24-29; p. 10 line 1-16, p.11, line 29-30, p.16 lines 18-20, etc.: very colloquial language).

p.4 line 1-14: Please include a conceptual sketch of which kind of cloud layers you are considering indicating minimum depth of the layers, minimum vertical spacing between two supersaturated layers with a subsaturated layer between, temperature restrictions. . .otherwise it is really hard to follow.

p.4: It is mentioned that a simplified approach is used to determine the capacitance for a hexagonal plate. (By how much) does the capacitance differ for different ice crystal shape assumptions (columns/dendrites/quasi-spherical spheres)? Also, why do you use a radius-volume relation of a sphere (p.5) if you consider hexagonal plates? As e.g. shown by Mitchell, JAS 1996, ice particle fall speed is a strong function of ice particle shape and density. Only assuming one particular ice crystal shape (hexagonal plates) is not sufficient for the fall distance estimation. Sublimation calculations should at least be repeated for two other ice particle shapes with very different fall speed characteristics such as columns and dendrites which would lead to very different fall distances. Additionally, please mention the influence of up- and downdrafts on ice particle fall velocity and thus fall distance.

p.6 line 24-29: Very colloquial language describing the radar reflectivity above the detection limit (p.6) - please rephrase. Please describe you averaging more in detail: I assume you refer to temporal averaging at each altitude? Please include a third Panel in Fig.2 showing the radar reflectivity sensitivity profile and the averaged reflectivity of the example case (for 50% data points within the considered time span).

p.8: I haven't seen a definition for a cloud case – how long of a gap in time is needed to refer to a scene having two separate clouds at one altitude– one radar profile (30s?) or a few minutes? Or is this not considered at all and averaging over time around RS launch is done in a way that separate cloud occurrences at one height are averaged into "one"?

p.10 lines 1-4: I do not fully agree with your conclusion that no cloud return in the radar data always means cloud-free conditions. There could be situations in which the sensitivity of the radar is not high enough (LWC and IWC too low). – I thus strongly suggest to also use available profiling lidar data (ceilometer) instead of only radar data to check for cloud occurrence in supersaturated conditions. Although the ceilometer suffers from full attenuation at sufficiently optically thick clouds, it will likely increase the number of detected cloud occurrences from ground-based remote sensing observations.

Moreover, in the Arctic frequently clouds occur at very low altitudes which might sometimes be below the lowest radar/lidar range gate. On page 16 (line 15-16) you mention that a lidar would be useful. I strongly suggest making use of the existing ceilometer data (https://www.awipev.eu/awipev-observatories/cloud-cover/) in your study.

Minor comments ——————-

Title: I suggest adding “in Svalbard” to narrow down the geographical range of the study. Also, since you are only considering T< 0°C, you can add “cold” clouds in the title.

p.4: For all variables in the equations the units should be included.

p.1 Line 10-13: It is unclear which kind of “deviations” you refer to – please specify more in detail.

p.1 line 16: it should be “improve” instead of “improved”

p.1 line 16: hydrometeor shape and density (and thus terminal fall velocity) are of great importance, too.

p.1 line 21: You could add that the typical structure of stratiform mixed-phase cloud with supercooled liquid top layer and precipitating ice points to heteorogeneous ice formation processes (add citation).

p.1 line 21: rather from the “remote sensing point of view” p.1 line 22ff: “variable lidar signals inside a more or less continuous radar signal” sounds very imprecise – please rephrase and refer to “cloud profiles obtained with vertically-pointing instruments” or sth. similar

p.1 line 24: make it easier for the reader and put multilayered vs. multilayer in Italics or bold font

p.1 line 24: In which measurement is the interstice of multilayer clouds visible – in profiles of radar or lidar or both?

p.2 line 2: I suppose, you mean “at least” two clouds in different heights since there can be very low boundary layer clouds, midlevel clouds, and high-level clouds occurring simultaneously

p.2 line 20: Please modify the sentence since you look at one specific Arctic site (. . .occur at Ny Alesund not “the Arctic”)

p.2 line 20: Why “thereby”?

p.2 line 22: it should be “ground-based remote sensing” measurements

p.2 line 23: What do you mean by “easily accessible”?

p.2 line 25: be more precise in your wording: Instead of “radar” it should be profiling/zenith-pointing Doppler cloud radar

p.3 line 20: Please give a rough estimate of horizontal drift of the sondes based on their GPS tracking.

p.3 line 23: Please also indicate the lowest radar range gate and mention that the cloud Doppler radar is zenith-pointing. You mention a vertical radar range gate resolution of 20m, is it really the same at all altitudes (i.e., all chirps) and was the RPG radar really operated in the same mode (with the same vertical and temporal resolution) over the entire year? 30s temporal resolution seems very low – please verify this temporal resolution. . .or are you using data already averaged to Cloudnet temporal resolution?

p.3 line 25: Please indicate typical values of attenuation correction for the 94GHz radar at Ny Alesund.

p.3 line 25: What do you mean by “at all frequencies”?

p.6 line 4: ice crystal size r refers to maximum dimension? Motivate the choices of ice crystal size of 50/100/150 microns by citing typical values found in Arctic clouds.

p.6 line 4: It is unclear what you mean by “mean conditions”: Mean over one hour after radiosonde launch?

p.6 line 5: “survive” is very colloquial, please replace or describe what you mean. Please change accordingly throughout the text.

p.6 line 17: The way it is presented it sounds like as if the radar is used to test for cloud occurrence (above/between/below) in general and not only for cloud occurrence in general (Also see Table 1). (?)

p.6 line 19-20: Clarify why you use 30min after the radiosonde reached 10km as end time and not e.g. simply a one hour time around RS launch (start 30min before and end 30min after launch)?

p.6 line 29-30: “Evaluated” in which way?

p.6 line 31: 50% of what? Of all pixel within a 100m x time from RS launch to 30min after RS end? Or 50% of pixel at a certain altitude?

p.6 line 34: Specify that the ice crystal is actually growing in the supersaturated layer and which microphysical growth processes could occur and specify in which way the ice crystal can “influence” the cloud.

p.7 line 12 -13: Why do you refer to seeding situations here when you describe non-seeding situations in line 10-11?

p.9 line 8-10: Describe the influence of varying ice crystal size more in detail: 57% of possible seeding for 150micron ice particle size and only 37% for 50micron. . .

p.9 line 11: Please expand your discussion of Figure 5. In number indicate the number of cases considered for each month (February maybe has a much lower number of cases?).

p.10 line 2: Define acronym IN(P)

p.16 line 2: vertically-pointing cloud Doppler radar (instead of only "radar")

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