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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Ice particle properties of Arctic cirrus" *by* Veronika Wolf et al.

Anonymous Referee #1

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1. Overview of the paper:

This paper presents balloon borne in situ measurements of cirrus clouds over the Kiruna region. Eight "flights" are analysed to derive the vertical distribution of microphysical properties (shape, size, and number concentration of ice crystals) of cirrus. Cirrus clouds are classified according to their origin: namely in situ-origin or liquid-origin. The main results show a variability in particle size, shape and to a lesser extent number concentration. This variability seems to be mainly connected to the cirrus origin. The observations presented in this study are useful and the topic is relevant. New measurements of the vertical properties of ice crystals within cirrus clouds are important, especially if they are combined with information on the dynamical state of the atmosphere. I like the idea of linking the microphysical properties to the in situ or liquid origin of cirrus. It gives researchers a framework for comparing cirrus properties in different region of the world and to understand dynamical process responsible for the

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Discussion paper

formation of cirrus clouds. The balloon-borne observations of the vertical distribution of cirrus microphysical properties are potentially very useful for the community. However, a more thorough data analysis and a better presentation of the results should be done before considering the publication of the paper in ACP. I would recommend major revisions.

Below I have compiled a list of general comments and more specific comments that should be considered (hopefully) in a revised version of the paper. Not all are mandatory but I have the feeling that at least some could help to improve the readability of the manuscript.

2. Major comments:

Data analysis and interpretation

I have the feeling that the authors could do a better job in the analysis of their measurements. The results are not always presented in a clear and coherent way. Sometimes, the data analysis does not fully support the conclusions drawn by the authors. All the measurements should be presented and compared (figure 5 and figure 6). Most of the main findings are based on only 2 or 3 cases. A more thorough interpretation of RADAR and LIDAR observations should be done to support the conclusions. The main conclusions on the impact of cirrus origin on microphysical properties should be detailed. The authors jump to conclusions without discussing (or showing) the entire dataset. I also would expect a small discussion including comparison with previous findings at mid latitude and in the Arctic. The authors should also explain what is their definition of a cirrus clouds since ice layers at -20C/2000m are considered.

General structure of the paper :

The text is sometimes not easy to read. I would suggest that the authors seek for an additional proof reading. As I am not a native English speaker (as you can see), I will not go into details to point out grammar errors as I might be mistaken. The general

structure of the paper could be modified to improve the manuscript clarity. Some figures would need a more thorough discussion and interpretation. I would reorganise section 3 and section 4 to focus on the results of the study. Then, a section called “discussion” should be added where the results could be compared to previous findings at mid latitude and in the Arctic. Lidar and Radar measurements should be presented in this section and a more complete analysis should be performed. Finally, the last section should be called summary and conclusions.

3. Specific comments :

0. Title

“Ice particle properties of Arctic cirrus” might not be the most appropriate title for this study. I would recommend the authors to be more specific as the case studies presented in the paper are not proven to be representative of all cirrus found in the Arctic. An alternative title could be “Vertical microphysical properties of Arctic cirrus over the Kiruna region (68°N, X°E)”.

1. Introduction

The introduction could be significantly improved to deliver a clearer message. Editing and reorganisation of sentences and paragraphs would be appreciated. Some statements/sentences should be clarified and completed.

Page 1 - Lines 21-22: I think that you should state the main questions to be answered here. For instance: What are the sedimentation velocities and the optical properties as a function of the ice crystal shape and complexity? What is the relationship between IN and ice crystal concentration? How is the vertical distribution of size and shape in cirrus clouds? What is the contribution of small ice crystal (D<50μm) to the IWC? What is the spatial scale of cirrus properties inhomogeneities? Etc...

Page 2 – Lines 3-5: Are you sure that IPCC points out that the improved knowledge of cirrus clouds properties in the arctic is a priority. I think that low level clouds such as

mixed phase clouds are also a large (larger?) source of uncertainties in models. You might want to slightly change that sentence.

Page 2 – Lines 6-8: There has been a lot of airborne campaigns carried out in the Arctic focusing on clouds or aerosol-cloud interactions. Recently, ACCACIA-2013, ACLOUD-2017 were performed in the European Arctic region. POLARCAT 2008, ASTAR 2004 & 2007, SORPIC 2010 also took place over the Norwegian Sea- Greenland Sea region. Other campaigns were also undertaken in the Western Arctic region such as: ISDAC-2008, M-PACE 2004, FIRE-ACE 1998, ARCPAC 2008, VERDI 2012, RACEPAC 2014 . . .. Some of these campaigns should be cited in the introduction. They might not have focused on cirrus clouds but I'm pretty sure that some measurements of cirrus cloud properties were performed

Page 2 – Lines 9-10: please rephrase and shattering should be introduced later in your introduction (see comments below).

Page 2 – Lines 12-18: This paragraph is important as it presents some of main results from modelling activities as well as some of the key properties to assess. It should be moved to line 5-p2 or page 1.

Page 2 – Lines 25-30: This paragraph should be positioned before the paragraph on airborne measurements. Moreover, it would be good if you could briefly summarize the main results obtained by Lynch et al..... Kramer et al. . . ..

Page 2 – Line 34: Could you be more specific when you write "the analysis focuses on ice particle and cloud properties" ? What do you mean? ice crystal shape and size ?

2. Campaign description

2.1 Location

Page 3 – Lines 5-9: At this point, I would recommend giving more details on the meteorological conditions (synoptic and maybe local), to discuss the influence of the Scandinavian mountains on cloud formation and properties and to describe more precisely the

measurement period (indeed, measurement days are mentioned but are not indicated at this point).

2.2 Measurement methods

Page 3 - Line 11: “for the measurements of cloud and particle properties” what do you mean here by particle properties? I did not see any aerosol measurements in the paper? Or do you mean cloud particle properties? You should also specify that the in situ imager is balloon-borne. Some details should also be given on the type of balloon.

2.2.1 In situ imager

Could you give more details on the sampling method, efficiency, shortcomings and potential measurement errors linked to the instrument and the fact that it is balloon-borne?

Does the in situ imager has a name? Maybe you should replace in situ imager by cloud particle imaging probe. What is the weight of the instrument?

Page 3 Lines 23-24 : I think you should use the past tense in this sentence (was / were instead of is/are). What do you mean by partly manually partly automatically? Could you be more specific and elaborate on the reasons why this cannot be done with a fully automatic algorithm (are you talking about the ice crystal shape classification or pre processing of the data to check for acceptable non distorted images etc, see also my comment on figure 2) ?

Page 3 Line 25 : What do you mean by “Once the particle outlines have been traced”?. You should also explain briefly how the microphysical parameter were calculated from your images and with which accuracy.

Page 3 Line 27 : “smallest diameter of the circle that encloses the whole particle” is this the diameter of the smallest circle that encloses the ice crystal? Could you give some references on how this maximum dimension compares to other diameters used in Optical Array Probes ?

Page 4 Line 1 : Compact particle are spheroidal : ok but you might want to use spheroidal in the abstract to avoid any misunderstanding.

2.2.2 Radiosonde, LIDARs and RADAR-LIDAR

I have the feeling that LIDAR and RADAR data could be more thoroughly exploited to complement the cirrus in situ measurements (in a discussion section for instance). As mentioned by the authors, those measurements can be used to describe the dynamical properties of the atmosphere. These additional measurements experiments would strengthen the main findings of this paper. In the present form of the paper, I don't really see the added value of such measurements (the lidar figure is not described and the radar figure needs a better description/analysis : see comment section 4 and figure 7)

Page 4 Lines 15-16 : "Radiosonde data, temperature, humidity, height and geographical coordinates can be assigned to each particle" : this sentence does not sound right. The use of the word "particle" is ambiguous. Do you mean cloud layer with a 60m vertical resolution?

Page 4 Line 24 : You should shortly sum up the main results of the in situ imager – Lidar extinction coefficient comparison. Otherwise, I don't understand the meaning of this sentence.

3. Classification of measurements

3.1 Cirrus origin

Table 1 Page 5 and Line 11 Page 6 : Table 1 is interesting but I think average Temperature and Altitude values could also be mentioned here. Could you also explain in the text which kind of weather maps and satellite images were used to describe the meteorological situation?

Figure 2 Page 6 : You mention latter in the text that the assignment between irregulars and rosettes was sometimes ambiguous. What about plate and compact spheroidal

ice crystals?. Looking at figure 2, I can imagine that it is quite hard to discriminate small compact crystals from small plates. It looks like the shadow of the coating is distorted/modified by the impact of the ice crystal on the coating. It might result in an increase of the degree of "roundness" of the ice crystal, meaning that if an automatic classification algorithm is used small ice plates could be classified as compact ice crystal (explaining that you find almost no plates in your cirrus cases). Am I wrong? Could you discuss mis classification issues? You should also show the size of the ice crystals on figure 2.

Page 6 Lines 4-5 : I think a verb is missing in this sentence, please consider rewriting this sentence.

Page 6 Lines 6-10 : You might want to clarify this paragraph. I know that you are not supposed to fully describe the methodology described in Kramer et al., 2016 and Luebke et al., 2016. However, I think it is still necessary to elaborate on this cirrus classification as it is linked to the in situ microphysical properties.

3.2 Weather conditions

Page 6 Line 13: What are the average cloud heights ?

Page 7 Line 3 : I see that now the RADAR ESRAD is mentioned and used to detect the occurrence of Lee waves or gravity waves. For my personal understanding, could you explain me how this is done?

3.3 Cloud properties

Table 2 : Table 2 is not easy to read and does not look very "attractive". But it is still quite important. I would recommend modifying it or maybe transforming it into a graph (if possible). If you want to keep that table, please use the same date format as the one used in table 1, use colours according to the air mass origin (in accordance with figure 3).

Page7 Lines 7-10 : I'm getting lost here, I don't understand how a cirrus could have

a geometrical thickness of 6km and a cloud base close to 2km (and temperature of -11.5°C). Could you elaborate on the cirrus definition used in your study ? These two thick clouds have a liquid origin and are associated with southerly winds. Looking at Kramer et al., ACP 2016, and Luebke et al. 2016 I can read that liquid origin cirrus are characterized by : (1) high IWC, high ice crystal concentration (NC>100 L-1), and large ice crystals (D>200μm) (2) nucleation mechanism is probably homogeneous freezing (low IN) (3) Fast updrafts (4) They appear with liquid containing clouds below

From your results presented in table 2, we can see that the ice crystal size is on average larger for liquid origin cirrus but the ice number concentration is very low (especially for the 01.04.2015 & 12.02.2016 case). How do you explain this? It doesn't not seem to agree with mid latitude results presented in Kramer et al., 2016 and Luebke et al., 2016. I'm also wondering if the low layers considered as cirrus clouds correspond to mixed phase clouds, glaciated clouds or fall streaks? How can you tell that low level cloud layers are solely composed of ice crystals : you have no cloud droplet measurements ?

Page 10 - Table 3 : Table 3 displays the distribution of ice crystal habits within each "flights". It is interesting but hard to compare. An indication of the temperature and relative humidity with respect to ice should be provided along these values. A vertical distribution of the cloud shape would also be more valuable. In your statistics you are "mixing" ice crystals measured at 2000m/-11°C with ice crystals found at 8000m/-54°C and compare it to ice crystals found at 11km/-65°C ? Is this relevant ?

In in situ cirrus, the fraction of compact ice crystals seems to be high (40% to 70%). Is this in agreement with previous results found in cirrus clouds? The fraction of plate is very low but don't you think it is due to a possible misclassification of small plates to compact ice crystals. Once again, this should be discussed in the paper.

4. Results and Discussion

4.1. Size and number concentration

Page 10 line 3 : “see observations 2” : what does it mean ? Maximum size displayed on table 2.

Page 10 line 5 : “At three of the four days” should be something like “During three of the four days”

Figure 5 – Page 12 : I think that you should show your results in log-log scale (with dN/dlogDmax vs Dmax for instance) – not mandatory as you might not see the difference (broadness of PSD) highlighted in the paper. However, I think an additional panel where the PSD measured at comparable temperature should also be shown. It would help support your main conclusions regarding the differences of PSD behaviour found for liquid origin cirrus and in situ cirrus.

Page 10 Lines 11-15 : It would be good if you could rephrase this paragraph to help the reader understand your point. “vastly” should be significantly. The fact that the PSD is narrower with increasing height and decreasing temperature is clearly evidenced on the in situ cirrus case. Size is decreasing and NC is increasing. The PSD is very narrow and almost look like monodispersed distribution, is it really representative? Is it due to sampling issues? This temperature/altitude trend is not clearly seen for the liquid origin cirrus case. Why ? Do you have microphysical process hypothesis to explain this behaviour?

Page 10 Line 16 : “While these differences are obviously not related to local ambient conditions, they are related to the cloud origin” : this statement might be a bit strong. Without showing additonnal cases, it is hard to be so positive... What about humidity measurements? I did not see any in the paper. It could be useful to better interpret your dataset.

Page 10 Lines 17-18 : Gayet al., 2007 focused on a case study where observations of ice crystals precipitation (from cirrus ?) down to a supercooled boundary layer stratocumulus were made. Measurements were performed at 1500m/-11°C. The PSD shows ice crystals with size ranging from 25μm to 1000μm with a Deff=270μm (and NC=10

l-1). I understand that in situ measurements in arctic cirrus are scarce but this study is hardly comparable to your study. At least you need to be more precise in comparing your results, do you mean that you are comparing the PSD of precipitating ice crystals (which case is this in your study ?) to Gayet et al., work ?

Page 10 Lines 21-23 Yes, I agree that the number concentration of ice crystals found in this in situ cirrus is higher than in the liquid origin cirrus. This is not in agreement with previous findings of Kramer et al. and Luebke et al.. I think that all your cases should be presented on Figure 6. It would be easier to see if the vertical profiles are linked to the in situ/liquid origin or the air mass origin. It is hard to draw conclusions based on two very specific cases.

Page10 Lines 23-24 : "It should be noted that the y axis .... in concentration" : you could delete this sentence.

Page 11 Lines 1-5 : Fig 6 is very important but I don't understand why only two cases are shown. If possible, the 8 flights should be plotted on this figure. You also say that two cases (half of your in situ cirrus events) of in situ origin cirrus cloud (20/02/2013 & 15/03/2016) exhibit high ice crystal number concentrations, sometimes much higher than concentration found in liquid-origin cirrus. It is true for the 20/02/2013 case but I don't think this the case for the 15/03/2016 where concentration is close to 11-14 l-1 on average (according to table 2). Some cases of liquid-origin cirrus reach 56 l-1 and the 04/04/2012 in situ origin cirrus concentration reaches 131 l-1 at 7km. So, I don't understand your comparison. Please, clarify this point as it does not make sense to me. Once again, this also shows that each profile should be plotted on this figure to facilitate the comparison and draw solid conclusions.

Page 11 – Lines 9-11 and figure 7 : It is a good idea to use lidar and radar measurements but I think that you need to go more into details. You show the vertical profile of the extinction coefficient measured from the LIDAR but I don't see the added value of such plot : nothing is said about it or compared (extinction, altitude, structure of the

cloud...). What about the lidar and measurements performed during the liquid-origin cirrus event?

Page 11 – Lines 10-11 figure 7 : Without a more detailed explanation it is hard to see/understand how wind vertical velocity measurements below 5km can explain “waves with high velocities can explain such higher number concentration”. Please clarify this.

Page 11 -Lines 14-16 : This could be an explanation, indeed. From your results, one can see that the ice crystal sizes agree with Luebke et al. But not the concentrations. The reasons for such discrepancies should be discussed and your results should be compared to other measurements in cirrus clouds (at mid latitude and in the Arctic if there were any). I also have the feeling that the vertical distribution of Nc is much more variable for in situ origin cirrus than for liquid origin cirrus, why ? Don’t you think it is a problem to compare cirrus properties at very different altitudes ? I think that you sometimes compare fall streaks, high and cold cirrus (-66°C-10000m), with warm low ice clouds (-11.5°C -2000m) ?

Page 11 – Line 16 : should be “Arctic region”

4.2 Shape

Page 11 Lines 20-25 : This paragraph is more a discussion than actual results. It should be moved either to a new discussion section or to line 10 p 12. Your paragraph should start with “The frequency of occurrence of the different particle shape... line 26.

Page 12 Line 6 : “this corroborates findings by others” : which findings ? be more specific. It is important to compare your results with other measurements. For instance, I am surprised to see that rosettes are mainly found in liquid-origin cirrus, at which temperature? . My question is : Do you really think that the shape of the ice crystals is more likely to be influenced by the origin of the cirrus (meaning in situ or liquid) or the temperature and Rhi ?

Page 12 Lines 5-10 : please rephrase this paragraph, I don't understand what you are trying to show.

5. Conclusions

Page 13 Line 7 : "when looking at the cirrus in terms of its origin, similarities between the various properties are striking" : I don't understand what you mean here : you are saying just above that large differences in ice particle size, shape and number are observed and then that similarities are striking when looking at the origin of cirrus.... please rephrase.

Line 8-9 : I think this sentence should be placed after the summary of the most important results.

Page 14 : I would suggest to also summarize the comparison between your work and previous studies using the same cirrus classification.

Please also note the supplement to this comment:
https://www.atmos-chem-phys-discuss.net/acp-2018-386/acp-2018-386-RC1-supplement.pdf

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