Coincident In-situ and Triple-Frequency Radar Airborne Observations in the Arctic

1 General comments

This is an interesting paper presenting triple-frequency radar observations collected from an Arctic region using X, Ka, and W band radars on board an aircraft, along with microphysical measurements. The NRC Convair-580 aircraft carried the NAWX and KPR radars, along with an array of in-situ and remote sensing sensors. This is different to previous campaigns which usually don't make all the measurements from the same platform.

The authors consider the best way to treat the data, and whether data should be taken from above or below the aircraft. This is done by simulating Z using in-situ PSDs, and comparing to measured Z.

The authors use machine learning to classify CPI imagery into particle habit groups. They also look at imagery from the HVPS3 probe. They then explore where the signal from the various groups is located in triple frequency space, in particular focusing on the relationships between DFRs and MVD and effective bulk density.

Some suggestions are outlined below, there are a lot of points but most of them are minor grammatical corrections. I request that the font size is increased on some of the plots. Moreover, some of the conclusions need to be clarified as the claimed relationship between bulk density and DFR is not obvious to me. Nonetheless, I thoroughly enjoyed reading the manuscript, and look forward to seeing it in its final form.

We would like to thank the reviewer for many detailed comments and great suggestions which helped improve the manuscript greatly. We have made significant changes in the manuscript and added new figures. We have also reprocessed the Nevrozov data which is now slightly cleaner and recalculated of the bulk density. The discussion of the relationship between bulk density and DFRs has been revised.

We hope these changes make the paper easier to follow.

2 Specific comments

Line 12- I think you need to clarify the opening line of the abstract. If I have understood correctly, this is the first dataset where the airborne radar and microphysics data were collected from instruments on a single aircraft, allowing for very accurate co-location. Other campaigns such as OLYMPEX have collected airborne triple-frequency and microphysics data, but the difference is that the instruments were

mounted on 2 different aircraft, so the co-location is less accurate. To me, the opening line of the abstract sounds like you are claiming that nothing similar has ever been done before. Or, is the novelty that the measurements presented here were made in an Arctic region?

We agree with the referee on this comment. We have revised the text in the abstract to make this point clear.

Line 39- Le et al, should this be Leroy?

The reference is Le et al. (2016). We apologized for the missing reference. It is now added to the manuscript.

Le, M. and Chandrasekar, V.: Enhancement of dual-frequency classification module for GPM DPR, in: 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), IGARSS 2016 - 2016 IEEE International Geoscience and Remote Sensing Symposium, https://doi.org/10.1109/igarss.2016.7729550, 2016.

Line 52- I think it would be useful in this paragraph to point out that triple frequency radar measurements have been made using ground based campaigns (e.g. TRIPEx; Dias Neto et al., 2019). The introduction of that paper provides a nice, concise summary of what has been done before, with relevant references. The PICASSO campaign in the UK has also been making ground based triple-frequency measurements along with coincident in-situ aircraft measurements of the microphysics. The co-location is very accurate as the radar dish is steered automatically using the real-time position feed from the aircraft. However, this work has not been published yet. For example see:

1) http://blogs.reading.ac.uk/weather-and-climate-at-reading/2019/improving-model-representation

-of-cloud-ice-using-cloud-radar-and-aircraft-observations/

Or

2) https://ams.confex.com/ams/15CLOUD15ATRAD/webprogram/Paper347299.html

We thank the referee for providing those references. We have mentioned those ground based campaigns to the revised manuscript.

Line 65- reference to Fig. 1: Firstly, the figures seem blurry to me. Secondly, in the figure captions here and elsewhere, I would prefer the reference to the subpanel to come before the description, i.e. “(a) Full flight path” instead of “Full flight path (a)”. Thirdly, the last thing you mention before referencing Fig. 1 is the altitude, yet this is not shown in the figure as far as I can see. Are the colours in Fig. 1a showing altitude? If so, this needs a key.

We received comments from other reviewers on this figure and figure 5 and 6. Because they are not necessary for the paper, in the revision, we have removed them and amended the text.

Line 71- Reference to Fig. 2 should be Fig. 3. Suggest switching Figs 2 and 3, as Fig. 2 (the triple freq plot) has not been discussed at this point in the manuscript.

We thank the referee for this comment. The error has been corrected. We have moved Fig, 3 to the introduction section.

Line 95- Should be kf2 − kf1 in the attenuation bracket.

We agree with the referee. Correction has been done.

Line 111- do you mean corresponds to leaving the Rayleigh regime as the particle size increases?

Yes, it is correct. We have modified the sentence for clarity.

Line 112- You point out that the shape and degree of riming of particle models contributes to the differences seen on the triple frequency plot. It is true that there is variability between particle models, but it is worth noting that some of the differences seen here result from the fact that the size range of your particle models is not the same. For example, the sizes of the ice sphere in the ARTS databases go up to 50000μm, while some other particles such as the small column aggregate and GEM cloud ice only have sizes up to 3000-4000μm. Moreover, the scattering calculations are done using different methods which will make a difference (e.g. DDA vs SSRGA). For example, see Fig. 11 of McCusker et al. (2021) for examples of differences in DFRs calculated using different scattering methods:

https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/qj.3967

Yes, we agree with the referee's comment. Indeed the idea of plotting different scattering models from a variety of database was to account for the variability of different methods (as highlighted by e.g. Leinonen et al. 2017; McCusker et al, 2020). Different habits of course have different size range. With the new figure, where we have highlighted characteristic values of PSD characteristic size, it should be clear that certain habits cannot indeed support large sizes (for instance small column aggregate or GEM cloud ice do not have Dm at 4 and 6 mm).

Leinonen, J., Kneifel, S. and Hogan, R.J. (2017) Evaluation of the Rayleigh–Gans approximation for microwave scattering by rimed snowflakes. Quarterly Journal of the Royal Meteorological Society, 144(S1), 77– 88.

McCusker, K, Westbrook, CD., Tyynelä, J. An accurate and computationally cheap microwave scattering method for ice aggregates: the Independent Monomer Approximation. Q J R Meteorol Soc. 2021; 147: 1202– 1224. https://doi.org/10.1002/qj.3967

Line 132 (Table 1)- need degree symbol for W and Ka beamwidths. Could you clarify what ”Sampling resolution” is and how it is relevant to the processing of the data and subsequent analysis/results? It doesn't seem to equal the vertical range resolution, but it is not obvious why there are two numbers listed for each radar.

The sampling resolution (or range gate sapcing) is defined as $\tau_s = cT_s/2$ where Ts is the data sampling rate. In the cases of the X- and Ka-band radars, two different options of Ts was used.

Line 163- There are 2 items in your bibliography that “Wolde et al., 2019” could be referring to, and the “Nguyen and Wolde (2021)” paper you reference seems to be “Nguyen, Wolde and Pazmany” in the bibliography.

We apologize for this confusion. In the revised manuscript, we have changed the reference to:

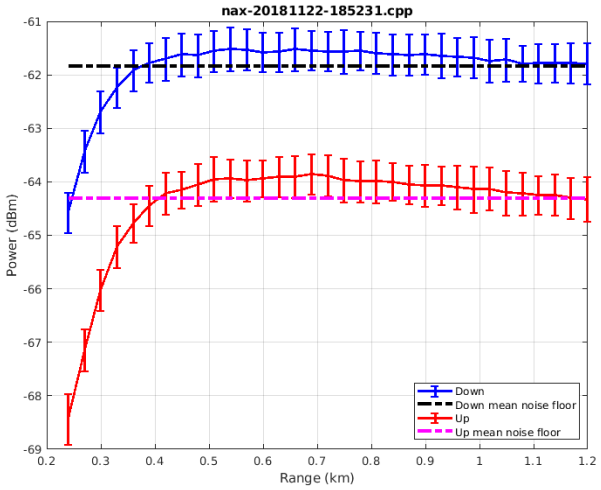
Nguyen, C., M. Wolde, and A. Pazmany, 2019a: The NRC W- and X-band Airborne Radar Systems: Calibration and Signal Processing, 39th Conf. on Radar Meteorology, Iraka, Nara, Japan, Amer. Meteor. Soc.

Line 168- It is clear from Fig. 4 that the radar profiles all match up nicely from 700m onwards, with mismatches at closer ranges. A height difference of 700m could be a big difference in microphysics so you want to use radar data that is closer to the aircraft, but in this region the data don't actually match. You select a range of 245m as W band attenuation is minimal, and claim in line 176 that the W band data is not affected by close range biases, and the offsets from the other radars are almost constant for each flight, meaning you can apply a correction for this to obtain an unbiased estimate of DFR.

Could you please address the following 2 related points:

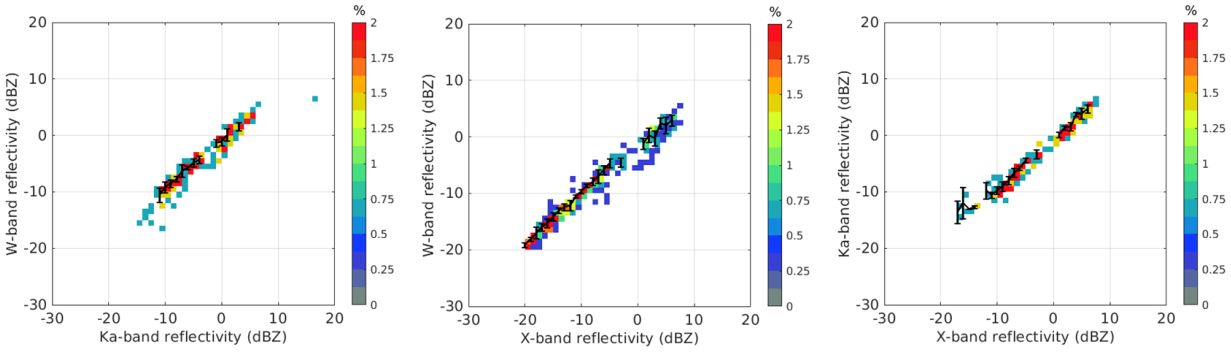
(1) You claim the data don't match in the close-range region due to limitations in the hardware. This is a bit vague, can you explain this is more detail, or consider other hypotheses and their plausibility?

In the time interval between the instant when the transmitter stops transmitting and the instant when the receiver reach to its steady state, the receiver gain can vary greatly. An example below demonstrates this phenomenon. It shows the system noise of the X-band radar as a function of range (or time). The X-band receiver gain should be stable within 1 dB standard deviation after 1 km. Usable range for the W-band (not shown here as we have to go back to raw data to generate a similar one) is about 200m.



(2) Can you show direct evidence that the difference between the two radars is consistent, and quantify the (hopefully small) variability, so that we know what the uncertainty on DFR is?

In the figure below, the scatter plots of cross-calibrated W, Ka and X reflectivities at 245 m from the nadir antennas for the 22 Nov flight are shown. The data are thresholded by MVD < 300um so that $Z_{Ka} \sim Z_X$ and $(Z_{Ka} - Z_w) \sim 0.2\ dB$ (Matrosov, 1993). The black lines are the mean and error bars (one standard deviation). We found that the standard deviation of the DFRs is 0.8 dB in average. We have included this information and these plots in the revision.



Line 180- reference to figure 10d, yet this figure is 7 pages later in the manuscript after many other figures that have not been referenced yet. Is it possible to reorder them to match the order they are referenced?

We have revised this paragraph and included the scatter plots (above) to make the presentation clear.

Line 192-194- rephrase this sentence

We have rephrased this sentence. It now reads “Bulk liquid water content (LWC) and total water content (TWC), measured simultaneously with a particle imager and spectrometers, were characterized by size distributions, ranging from small cloud droplets to large precipitation hydrometeors.”

Line 206- Are you referring to Figs 13, 16, 19? You could say “The fraction plots are presented in section 4”, or something similar, so the reader can find them easily.

We thank the referee for this comment. The sentence has been added.

Line 224- How did you come up with this value for the estimated value of Nevzorov data?

An uncertainty of about 0.05 g/m3 is present in the Nevzorov water content data due to uncertainty in the baseline ('dry term'), similar to results shown by (Faber et al 2018). With regard to LWC, in a post-campaign wind tunnel test, the sensor demonstrated standard performance for a Nevzorov probe, similar to (Schwarzenboeck et al 2009).

Faber, S., French, J. R., and Jackson, R.: Laboratory and in-flight evaluation of measurement uncertainties from a commercial Cloud Droplet Probe (CDP), Atmos. Meas. Tech., 11, 3645–3659, https://doi.org/10.5194/amt-11-3645-2018, 2018.

Schwarzenboeck, A., Mioche, G., Armetta, A., Herber, A., & Gayet, J. F. (2009). Response of the Nevzorov hot wire probe in Arctic clouds dominated by very large droplet sizes. Atmospheric Measurement Techniques Discussions, 2(3), 1293-1320.

Line 234- Is mIWC just the ice water content, if so why not call it IWC?

It is correct. We have changed m_{IWC} to IWC.

Line 236- I think you should remove the sentence “Both mIWC and V are computed for 1m3” and instead clarify units in the previous sentences. For example “mIWC (or IWC?) is the mass of ice inferred from the power dissipated on TWC and LWC sensors of the Nevzorov probe (Korolev et al., 1998), with units of gm−3. V is calculated as the sum of the volume of all particles within the PSD, with units of cm3m−3. Thus ρ_e has units of gcm−3”

We thank the referee for this comment. We have changed the text as suggested.

Line 239- Include the formula, e.g. equation 4 in Brandes et al., 2007. Leroy et al. (2016) describe calculation of MMD, not MVD.

We have added a formula for MVD. The error on the reference has been corrected.

Line 246- “whilst there were almost certainly no similar sampling point” Can you rephrase/clarify this? You could just say something like: “The case study we are looking at is from the 22 November 2018,

which we chose because larger values of MVD were more frequent than during the other 2 flights (Fig. 6)."

What we meant by "similar sampling point" is "sampling point in the non-Rayleigh region". We agree with the referee on making this paragraph simpler. In addition, figure 6 is not important for the paper and we have removed it. The paragraph has been amended to reflect the change.

Line 251 (Fig. 6 caption)- Change "particle diameter from PSD" to "MVD from PSD"

In the revised manuscript, figure 6 has been removed.

Line 280- The caption of Fig 7 needs more explanation. The black dashed line is just the 1:1 line? What do the solid black line and the bars represent?

We have added more information to the caption of Fig. 7. The black dashed line is just the 1:1 line and the solid black lines present the mean and error bar of one standard deviation at each DFR bin.

Line 294- Again referencing Fig. 10 which appears later in the manuscript, after some figures that have not been referenced at this point. Suggest move Figure 10 to appear earlier in the manuscript, and also increase the font size on the figure as it's not easy to read.

We agree with the referee on this comment and have fixed the issue with the figure order in the revised manuscript. We have also revised all the figures to improve their readability and presentation.

Line 300- I don't think Fig. 8b really shows this, the aircraft altitude is more obvious in Fig. 10a.

We have updated Fig. 8 with lat and lon lines and the aircraft elevation profile.

Line 320- There are 4 boxes, but I think you only look closer at 1, 2, 4. If this is correct please remove the third box.

Correction has been made as suggested.

Line 335- Might be helpful to label the boxes you are referring to in the figure.

We have numbered the boxes for clarity.

Line 349- I think you mean to refer to a different figure here.

We thank the referee for pointing out this error. It should be referred to Fig. 13. In the revision, we have combined both Fig. 12 and 13 into so the reader would be able follow the discussion easier.

Line 364- "remarkably mirrors" - I don't think this is very obvious actually.

We have changed the sentence to “For example the slight decrease in DFR values around the middle of section B (around 19:51 UTC) resembles the decrease in the relative concentrations of dendrites and rimed particles (Fig. 13, middle right panel).”

Line 365- You point out that in section C the aircraft sampled heavily rimed dendrites, large aggregates, and reduced drops. From the imagery it looks like unrimed dendrites are also present in section C. From the top particle fraction plot it looks like section C is mainly drops, small ice, and irregular ice, why does this plot not show many rimed particles? Likewise for section D. Perhaps it’s just too small an amount to be visible on the scale presented.

In section C, small drops, small ice, and irregular ice still dominate but the fraction of rimed dendrite, unrimed dendrites, and large aggregates increased compared to the second half of section B. We have revised the text for more accuracy. “Section C is from sampling of the storm when the aircraft sampled clouds with some heavily rimed dendrites and large aggregates as observed by the HVPS2 probe. The fraction of rimed dendrite, unrimed dendrites, and large aggregates increases and the fraction of small drops decreases compared to the second half of section B.”

Line 369- “In section D, mainly heavily rimed, fractured ice and frozen drops are present” - In the particle fraction plots in Fig. 13 for section D, it looks like “other ice”, “pristine” and “dendrites” are mainly present. There is a greater proportion of pristine particles than rimed particles, or am I interpreting the plot incorrectly? When you say fractured ice, are you referring to “other ice” in the groups in Table 2? Also, in the list of particle types for the “Other ice particles” merged group from Table 2, what does “ice” refer to?

We agree that the word “mainly” should be removed.

As shown in Table 2, ‘other ice’ includes ice crystals that do not fall under the other listed groups. Fractured ice crystals can fall into ‘other ice’ or a different group depending on their look, for example, a large part of a broken dendrite can be classified as dendrite, while a smaller part would fall under ‘other ice’. Fractured ice in particular was highlighted here based on the visual review of the CPI imagery, as can be seen in the example in Fig 13.

In Table 2, ‘ice’ refers to ice crystals that do not fall under other subgroups. ‘Tiny ice’ refers to crystals whose shape cannot be meaningfully classified because the images are too small (but >= 40 um). Other subgroup names are self-explanatory.

Line 372- Now you’re saying that in section D the fraction of rimed particles is at its lowest level, when you just said on line 369 that it was mainly heavily rimed particles?

We thank the referee for this comment. We have removed the word “mainly” and modified the sentence in line 372 to “It also shows a slight increase in the larger sizes whilst the fraction of dendrites and rimed particles drops to its lowest level at the first half of the section when the highest DFR X/Ka occurs”.

Line 380- Fig. 13 is a nice plot full of important information, but it is difficult to read as the font is blurry, and the HVPS imagery is also blurry. Can you enlarge the font size and the size of the figures? Also label the subpanels and refer to the labels in the text (paragraph starting line 351), rather than referring to the middle right panel, for example. In the MVD and ρe figure, the axes colours should match the line colours, otherwise you need a legend.

We have rearranged the Fig. 13 panel, increased the font size and labeled all the panels. We hope the modification would facilitate the reading.

Line 388- “DFR X/Ka decreases when bulk density increases” - This is not obvious to me, do you mean DFR Ka/W decreases?

We have reprocessed the Nevrozov data and recalculated the bulk density. The new results are slightly cleaner. We have also changed the colormap and display scale to better illustrate this observation.

Line 392- In the references, sometimes the year is in brackets and sometimes it’s not (here and elsewhere in the manuscript). I think the sentence would be easier to read if the references were given at the end of the sentence rather than in the middle. Maybe say “only aggregate models have been shown to produce a “hook signature” as observed in the data displayed here (List references).”

We thank the referee for this suggestion. We have made the changes as suggested.

Line 395- Change “heavily riming clouds” to “heavily rimed cloud particles”. But also consider whether this is actually the case, e.g. refer to comments for line 369 and 372. Perhaps it should be changed to “only a small proportion of rimed cloud particles”.

We agree with the referee. We have changed the text to “only a small proportion of rimed cloud particles”.

Line 397- Are sections A and E discussed?

The discussion for section A and E has been added in the revised manuscript.

Fig. 14- I really like the way the data is presented in these plots, although some of the pink/purple shades may be difficult to distinguish from each other.

We have revised this and other figures, employing a different colormap and reduced display interval for an improved presentation.

Line 404- Correct attitude to altitude. The black line in Fig. 10a is above 2km, is that the aircraft altitude? You say it's 1.7km here

We thank the referee for pointing out this error. It is 2.4 km. The error is now corrected.

Line 405- Another issue with figure order, Fig. 16 is referenced before Fig. 15, so suggest switching the order of these 2 figures.

In the revision, we have merged the two figures into one and checked for the figure order issue.

Line 410- Is the fraction of rimed particles and dendrites higher in section B than section C? The combination of orange, yellow, and purple sections in the ice only plot in Fig. 16 seems similar for B and C, if not bigger for C?

We have corrected this sentence. "In section B, the fraction of rimed particles is the highest.". The rimed particle fraction (purple and yellow) is the highest.

Line 412- What do you mean by "increased in land"?

We meant when the aircraft flew over land. This is not important for the discussion so we have removed the phrase "in land".

Line 418-420- Your summary of section A needs to be revised. You say MVD is between 2 and 4 mm, but maybe it should be more like 1mm < MV D < 4.5mm? Also, you say "for larger MVD (~ 6mm)", but looking at the MVD plot (4th panel down at left hand side of Fig. 16), the largest value of MVD in section A is less than 5mm.

We apologize for this confusion. We had updated the PSD calculation but some text was not changed. The error is now corrected.

Line 422-423- "peaked at ~10 dB...when MVD is greater than 8mm" - There are multiple points on the DFR curve in section B when DFR exceeds 10 dB, while there is only one point when MVD exceeds 8mm."MVD is greater than 4mm" would be more accurate, or perhaps you could rephrase to something like: "when MVD is large, at times exceeding 8mm"

We have fixed this error. The sentence is now read "… at times reached the same level as DFR Ka/W at around 8 dB when MVD is greater than 4 mm."

Line 427- You talk about overlapping data points between sections, but we can't see the boundaries. Is it worth putting boxes around the data points in each section?

In the revised manuscript, we have used different colors for the edge the dots to help identify sections A-C easier.

Line 428- Do you mean 0.12g/cm3?

Yes. The error has been corrected.

Line 428-430- You repeat the same thing in 2 sentences here, can you rephrase to be less repetitive?

We thank the referee for pointing this out. We have fixed this issue in the revised manuscript.

Line 430- You refer to Fig. 16 left panel - which plot are you referring to?

Fig.16- increase font size and label subpanels, refer to labels in text on page 17. Also do this for Fig. 19 and associated text

Figure 16 and 19 have been revised and all the panels have been labeled. The text has been revised to reflect the changes. We hope this make the manuscript easier to follow.

Line 449- You say around 2 dB, but around 2-4 dB would be more accurate

We agree with the referee on this point. Corrected as suggested.

Line 453- Should 2-10 be 2-12 dB?

Yes, it is correct. The change has been done.

Line 463- Is 2.9km correct? On line 445 you say 2.2km.

We have checked the data. On line 445 and 463, it should be 2.5 km. We have corrected this error.

Line 464- Specify that the increase in MVD is only at the beginning of the section.

We have added this information to the revision.

Line 470- I'm sure this will be fixed in later versions, but the figure caption of Fig. 18 is not attached to the figure and appears on a different page.

This issue should be fixed in the final print.

Line 499- I don't understand what you mean by the linear response comment, could you expand on this point please?

What we meant is the linear relationship between the DFRs and the MVD in the small MVD range. When MVD is large (e.g. > 8 mm), the scatter plot presents the "hook feature". We have revised the sentence for clarity.

Line 500- the saturation of DFR Ka/W is discussed in section 4 of Stein et al., 2015. You could perhaps link back to Fig. 2 here, as I don't think you have really made a connection between that figure and your results. Otherwise there is not much need for the figure.

In the revised manuscript, we have superimposed appropriate curves from the modeling work (Fig. 2) to the scatter plots to facilitate the discussion.

Line 503- Figure 21, not 22. Can you just provide a brief sentence explaining how you created these plots of mean MVD? In line 504 you talk about estimating MVD, but you have plotted "mean MVD".

The figure number error has been corrected. We have added a sentence to the figure caption to explain how we computed the parameters.

We have modified some sentence in this paragraph to make the point clear:

Line 505- bulk density decreases as X/Ka decreases and KaW increases- this is not obvious to me. Maybe bulk density decreases as X/Ka increases and KaW increases? Actually page 5757 of Chase et al. (2018) finds that ρe increases as KuKa decreases and KaW increases, as in Kneifel et al. (2015), but I can't see that behaviour from your Fig. 21b. Am I missing something?

As mentioned above, in the revised manuscript, we have improved the presentation of those figures. We hope it illustrates the bulk density rotation feature better.

Line 513- Can you provide references where these DFRs were connected to rimed particles with MVD less than 6mm?

No, we are not aware of. It is from our observations in the study cases.

Line 523/524- Rephrase this sentence beginning "Although..."

In the revision, we have removed that sentence as it is not important for the discussion.

3 Technical corrections

We would like to thank the referee for pointing out these errors providing some great suggestions. We have corrected all the errors and revised the text as recommended.

Line 22- there is a double period here, and no period at the end of the abstract. Actually, the abstract seems to be incomplete, unless you mean to say "the analysis shows that there are close relationships between the..."

Line 23- remove s from aggregations

Line 30- Change "its data have shown a great potential also for rain estimation and snowfall in particular" to something like: "its data have shown great potential for rainfall and snowfall estimation"

Line 35- performance is slightly improved

Line 46- multiple radar frequencies, rather than multi radar frequencies

Line 50- instead of "global distribution of the ice-phase precipitation and, therefore, enhancing our knowledge", I would say "global distribution of the ice-phase precipitation, thereby enhancing our knowledge", or "global distribution of the ice-phase precipitation and therefore enhance our knowledge"

Line 53- maybe "capabilities of", instead of "capabilities in"

Line 57- I think the bracket including a sentence along with references separated by commas should be tidied up. One suggestion: "...cloud microphysical data. For example, the OLYMPEX provides 2.2 hours of in-cloud data with Ku-Ka-W radar data and coincident microphysics (Chase et al., 2018; Tridon et al., 2019)."

Line 58- remove such

Line 59- remove comma after low-intensity

Line 64/65- suggested edit: covering a large geographical region and wide range of microphysical conditions

Line 71-75- You are describing what the dataset features, so the points need to relate to this. For example the first point should say "triple-frequency radar data" and the second point should say "data from state-of-the-art in-situ sensors". The second point should end with a semicolon rather than a period. In the third point there is an s at the end of atmospheric.

Line 79- Remove "on"

Line 88/89- Suggest editing this sentence to something like "The large variability in ice crystal properties such as density, size, and shape makes the interpretation of..."

Line 97- Should be "due to non-Rayleigh effects"

Line 102- Remove s from attenuations

Line 109- should be "particle scattering properties", not "particles"

Line 119- "via the discrete dipole approximation". μ = hasn't come out as a symbol. Need to say what μ is.

Line 130- provide the highest level

Line 152- Rephrase, suggestion: "Secondly, data from the three radars is..."

Line 153- Change "mapped into" to "mapped onto"

Line 168- change "within 700m from" to "within 700m of".

Line 173- Remove s from snow

Line 195- “For this work, the cloud particle size distribution...”

Line 198- remove space before period

Line 201- should be “determination”, remove s from determinations

Line 207 (Table 2)- remove comma after plates

Line 210- “The particle size detection range”

Line 219- Korolev et al., 1998- period should be after al, not after et

Line 226- calculating the total volume within the PSD

Line 227- Do you mean “and aid interpretation of parameters”?

Line 230- the measured PSDs (You are not just using one singular PSD, right?)

Line 232- Heymsfield year, 2004? Put a colon after defined as (rather than a comma)

Line 258- “In the literature, collocating radar and and in situ data is often achieved”

Line 259- finding the nearest airborne radar data points to the in situ measurements

Line 264- on the same platform

Line 265- The temporal sampling rate. Here and on line 269- I don’t think there is a section 3.1a and 3.1b?

Line 267- I don’t think decimated is the right word, do you mean the radar data is degraded?

Line 271- Remove comma after first

Line 277- in the two directions

Line 287- the equivalent reflectivity factor

Line 288- Rayleigh-Gans

Line 289- Sometimes you write “X-band” and sometimes “X band”. Please keep this consistent.

Line 290- scattering effects

Line 303- and densely rimed particles

Line 304- Replace Figure with Fig.

Line 312- (Fig. 9 caption) temperature was in the range

Line 330- Reference to non-existent section 3b, do you mean 3.3.2?

Line 338- (Fig. 11 caption) replace PDFs with pdfs

Line 340- temperatures

Line 344- do you mean “based on”?

Line 344- Fig. 12 shows

Line 351- remove ’ from panels

Line 366- change “it is worth to note” to “it is worth noting”

Line 368- rephrase “an increase in dendrites portion”. Do you mean “an increase in the proportion of dendritic ice habits”?

Line 389- Change “numbers of concentration are” to “the number concentration is”

Line 390- Change “the section B and C data placement” to something like “the location of data from section B and C in the triple-frequency plane”

Line 394- attributed to

Line 413- Rimed particles and dendrites

Line 419- Move “respectively” to the previous line, after ~ 6 dB.

Line 452- millimetric needs another l. Also, should it be 2mm rather than 3mm?

Line 455- Change 6000 microns to 6mm for consistency with previous units.

Line 457- Change DRF to DFR

Line 459- change boarder to broader. I think you mean to refer to Fig. 18? Change affect to affects

Line 460- Remove “continually” as the increase is for a short period of time and is not continuous over the remainder of the section

Line 461- Change aggregate to aggregates

Line 462- Remove “that”

Line 483- In the abstract and conclusion you say co-located, but in the main text you say collocated.

Line 484- Suggest rephrasing to something like: “provides an unprecedented dataset for studying multi-frequency radar signatures of snow/ice clouds”

Line 485- Perhaps rephrase to something like: "...3.4 hours when the scattering was non-Rayleigh for at least one of the radar frequencies"

Line 486- Rephrase to something like: "illustrated here using data collected from one flight during an Arctic storm..."

Line 487- remove "low" before pristine

Line 488- The dual frequency ratios (DFRs) are as large as 12 dB

Line 488- do you mean "appear to be dominated by" ?

Line 493- Remove s from provides

Line 495- If you take my suggestion for line 488, you don't need to spell out DFRs here

Line 504- Remove s from estimates

Line 510- double period

Line 514- the shape of the PSD also has noticeable effects

Line 528- Change "at reach" to "within reach"