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Interactive comment

Interactive comment on "Observing ice particle growth along fall streaks in mixed-phase clouds using spectral polarimetric radar data" *by* Lukas Pfitzenmaier et al.

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This paper reports spectral polarisation radar measurements within a rather complex ice cloud system, and subjects these data to careful analysis using a "fall streak reconstruction" technique. The main virtue of the paper is the effort to pull together all the measurements to reveal a story about the evolution of the ice particles. This story is qualitative rather than quantitative, but this is fair enough - most other studies of this kind in the literature have the same limitation.

I think this is well within ACP's scope. It's pretty well-written, the results and methodology used are of interest to the community, and the paper makes a worthwhile addition to the existing literature on this topic. I have a number of minor corrections below - I think the paper is publishable once these have been addressed.

We would like to thank the reviewer for the time and effort provided for the review. Lukas Pfitzenmaier, Christine Unal, Yann Dufournet and Herman Russchenberg.

Introduction page 2, line 8 onwards. You make a big deal here about how it's important to study precipitating mixed-phase clouds and melting of ice particles, linking the ice above the melting layer to the rain below. I saw very few links in your paper to this aspect. Essentially your focus is on the ice-phase bit of a cloud that happens to be raining at the surface. I suggest that you change the emphasis a bit here to fit better with what you are doing.

Answer) The focus is indeed given to the precipitating mixed-phase cloud. However in the investigated cases, the rain below is constantly taken into account as input to rearrange the reflectivity data based on the fall streak method (bottom-up approach, Section 5).

You also make a link here to attenuation and attempt to establish a dichotomy between cloud radars (W, Ka, X bands) and precipitation radars (C- and S-band), then latter being relatively immune to attenuation. This seems to be a link to motivate the use of TARA which is S-band. I personally think the distinction is overplayed, but I acknowledge that the longer wavelength has some advantages for the interpretation of the data. I'm not sure I would make such a big deal of it myself, but I leave that to the authors.

Answer) Thank you for this opinion. As mentioned above, the emphasis of this study is to analyze convective/stratiform rainfall cases with potentially high reflectivity values, and severe reflectivity difference due to attenuation (see comparison MIRA and TARA in Figure 4).

Studies by Bader et al, Field et al were S-band not C-band.

Answer) This is corrected in the paper.

You might consider adding Keat et al (2017, JGR) to your review of relevant literature here. http://onlinelibrary.wiley.com/doi/10.1002/2017JD026754/abstract again identified oriented pristine crystals and inferred the presence of supercooled liquid water. Seems relevant to your case 2.

Answer) Thank you for mentioning Keat and Westbrook, 2017, we missed this article, which is now read and referenced in the article.

Section 2.

page 4, line 30,31. You say cloud top from MIRA is at least 0.5km higher than the one from TARA. Always? Surely this is case-dependent. I suggest it is better to quote the minimum detectable dBZ at, say, 5km height for the two radars.

Answer) We emphasized in the text the case dependency of this observation.

Section 3.

The arrow at the bottom of figure 2 confused me. First because it points backwards compared to the evolution of the particles in the cartoons. Second because it implies ZDR goes down as the particles grow, but this is not the case in your vapour deposition cartoon where ZDR is maintained. So I suggest removing this.

Answer) Acknowledged.

Orientation of particles. This issue first arises in section 3 (line 14, page 5) but continues throughout the paper. The terminology you use here mixes two distinct physical characteristics: shape (where the idea of prolate, oblate makes some kind of sense) and orientation (which is completely distinct and controlled by aerodynamics). You use the term “prolate” to mean a particle which is broadly in the shape of a prolate spheroid, which has its long axis vertical. Conical graupel can be an example of this. But there are other particles (like needles) which are prolate in shape but have a horizontal preferred orientation. So I strongly recommend you disentangle shape and orientation here and in the rest of the paper.

Answer) Thank you for this comment. The text is adapted to be more specific on this topic.

Page 5, line 18. Say diffusional growth of ice happens when vapour diffuses towards the crystals instead of forming supercooled droplets. Why instead? It is perfectly possible to grow both if the supersaturation is large enough.

Answer) The text is adapted.

line 20 - during diffusional growth particles keep their characteristic shape. I would like some clarification on this. I can think of two obvious counter examples: (1) dendrites for example often grow wider and wider without thickening significantly, and can end up with aspect ratios of 100:1. (2) when an in particle falls into a different temperature from its earlier growth - e.g. rosettes grow plate-like appendages, columns get plate caps, etc. So perhaps you can be more direct in your meaning here, and what you are assuming which is actually critical for the analysis that follows vs general information.

Answer) The text is adapted.

line 23-30 These are relevant bits of literature, but personally I think the evidence is not so clear cut. Suggest softening the wording in this paragraph to explain these studies have suggested or indicated what nature might be doing. Then when you pick these ideas up later and find evidence to support rapid aggregation of needles for example, that also makes the contribution of your new results more apparent.

Answer) The text is adapted.

Section 4.

Page 6 line 2. The reference to the text books here is not necessary, you have already introduced these processes. There are a few other places in the text where I felt the

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referencing was repetitive (e.g. Westbrook et al 2007 on page 10, line 20) line 17-19 - recommend remove discussion about sZDR in rain. It is irrelevant to what follows and confused me when I was trying to understand this paragraph.

Answer) The references are removed as well as the discussion of the sZdr in rain.

line 23-29. I found this hard to understand. Is diffusion dominant in this scenario? Or aggregation? or both? could be clearer. the first line of the paragraph says "a signature of diffusional growth", but then there is lots of talk of aggregation.

Answer) The first line is now: Figure 3 b) depicts a signature of diffusional growth and aggregation in sZ and sZdr.

Figure 3 could potentially be annotated to help make it clearer - e.g. with text and arrows saying for example things like "rimed particles" "crystals growing from vapour" etc

Answer) We finally kept the Figure as it was, because the additional text made the Figure too busy and therefore unclear.

I think generally in section 4 it would help to be clear that this is your conceptual picture of how these processes play out in a typical cloud, rather than asserting these signatures are universal - which would require detailed evidence.

Answer) The last two sentences of the first paragraph of section 4 is now: It is pointed out that these sketches are meant to explain spectral signatures of a S-band slantwise profiling radar. Other radar setups may have different spectral signatures.

Section 5.

Fall streak reconstruction. Any strengths and limitations to the technique worth summarising here? (for reader who does not go back to your previous paper)

Answer) A small section is added at the end of the first paragraph of page 8.

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Page 8 line 13. “3 time bins” - can you specify in seconds please

Answer) This is done.

Section 6.

Page 8, line 18. “S-band radar profiler TARA” - repetitive. Already introduced.

Answer) The repetition is removed.

line 31-32. homogeneous wind conditions. can you be quantitative?

Answer) The values of the retrieved horizontal wind are in average around 22 m/s in the cloud. However, one can see that in some regions values up to 25 m/s are visible. Due to the fact that values up to 35 m/s are visible when the new air mass is moving upwards and the wind direction changes (Case 3), we assume the horizontal wind field in this case as homogeneous only above 3 km.

Panels in figure 6, 10, 12 could be neater. “differential reflectivity [dB]” label on fig 6 panel (e) is impinging on the panel next to it (f). Quite a mix of font sizes etc.

Answer) Differential reflectivity [dB] label on fig 6 panel (e) doesn’t impinge anymore on the panel next to it (f).

Page 10, line 10. “a supercooled liquid water layer...is identified”. How? From RH close to 100%? or some more sophisticated balloon-borne sensor. If the former do need to acknowledge this is not direct (but I do believe it).

Answer) Super-cooled liquid water is assumed when the temperature and the dew point temperature of the radiosonde launch match. In general, this is an indication for the supersaturation of water vapor in these areas. In the ice phase of clouds supersaturation of liquid water is also possible, which is assumed here if the relative humidity reaches 100%. This is shown in the light blue shaded areas in the Figure 9.

Talk a lot about needles in case 1. How do you define a needle? Do you count a hexagonal column as a needle?

Answer) A needle is defined as a prolate ice particle. An explicit distinction between needles and hexagonal columns using polarimetric radar observations is rather complicated and almost impossible. They both originate in regions with similar temperatures. Needles are generated if super cooled liquid is present while hexagonal columns are formed under supersaturation with respect to ice. The identification of needles is based on the given temperature and supersaturation detected by the radiosonde. The MIRA measurements confirm such particle shapes. However a 100% prove can only be given using in situ observations in this case. Nonetheless we are quite sure that our synergistic observation gives a good indication that we observed needle during Case 1.

In case 2 and case 3 there are parts of the sZDR spectra which are negative. However you also acknowledge that there is a lot of fluctuation in these sZDR values. This raises the question - what is the expected random fluctuation on a sZDR data point? Can you estimate that? I think that would help the discussion a lot if you could.

Answer) The variance of sZdr is large, and increase when the SNR and the copolar correlation coefficient decrease. To mitigate this issue, only data with SNR larger than 10 dB are considered. Further 3 consecutive Doppler spectra are averaged in time (hh and vv) for this study to obtain consistent trends in sZdr at different times and heights. Significant negative values are obtained in this case. It might be that during the growth process and due to turbulence some prolate particles are within the volume (sZdr spectrum at 2864 m). Nevertheless, the large negative sZdr are rather uncommon and there is a sharp decrease of the sZdr values at the edge of the spectrum, making them questionable. For the presented spectrum at 3055 m, due to nucleation and growth of the seeded particle from above the probability of prolate particle in the volume is higher. Also the drop into negative values is less sharp.

Page 12, line 27. “newly generated particles...lead to an increase of Z in the rain pattern below the melting layer". This wasn't obvious to me. Can you be more explicit how you determined this to be the case?

Answer) By analyzing the time height plots (Fig 4) and the spectral data discussed in Section 6 an increase of reflectivity in rain was observed. This increase seems to have a strong correlation with the Zdr band above that can be related to newly formed pristine ice particles (with defined shapes). One can also see a decrease on rain reflectivity when the discussed signatures (Zdr band) are not observed.

Page 13, line 13. 114730UTC. Similar format for time elsewhere. I've not met this way of expressing time before. I guess it is just HHMMSS but you mix this around in the text with the more usual HHMM. Can I suggest you clarify this somewhere.

Answer) The time information will be unified and clarified in the text.

Page 13, line 4 (and elsewhere). When you do the fall streak reconstruction, you talk about using a "cloud base height" of 2.25km (for example). These aren't really cloud base heights though (CBH is a physical characteristic of the cloud) - instead they are simply boundary conditions for the reconstruction. So suggest rephrase. In case 3 the choice of 2.25km seems almost immediately invalidated by your arguments for not analysing any data below 3km. Can you justify this?

Answer) The cloud base height is selected above the melting layer in precipitating cloud systems. The fall streak retrieval is optimized to analysis the cloud containing ice particles. Concerning Case 3, the data below 3 km are not analyzed because of the horizontal wind direction shear. In that case we cannot relate the microphysical properties of the particle population under investigation to the ones below 3 km related probably to another particle population. However the full fall streak retrieval can be obtained (homogeneous conditions are not required), but in that case cannot be fully exploited.

line 16. Aggregation. So aggregation is occurring 5-4km. But then why does it stop below that?

Answer) From the observations the main growth of the particles occurs between 5 km and 4 km. Considering the MIRA Doppler power spectra, the mean Doppler velocity slowly increases towards the melting layer, which means that aggregation continues (slowly) until the melting layer, as we could expect.

Please also note the supplement to this comment:
https://www.atmos-chem-phys-discuss.net/acp-2017-1032/acp-2017-1032-AC3-supplement.pdf

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