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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Rapid ice aggregation process revealed through triple-wavelength Doppler spectra radar analysis" *by* Andrew I. Barrett et al.

Anonymous Referee #3

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The authors present a method to quantify the aggregation process and retrieve the ice particle size distribution using three co-located radars. They showed that aggregation causes a rapid (less than 10 minutes) growth of ice particles from 0.75 mm to 5 mm in maximum size. They speculate that the dendrites dominate at -15 C with large aggregation efficiency (approximated to be near unity). Although the results are important and the manuscript is interesting, there are multiple issues that have to be addressed before the manuscript can be accepted for publication. My suggestions are explained below.

General comments:

- How do you distinguish between the ice particles and water drops? In pg 5, ln 21, you said that your case is an ice cloud. Elsewhere you mentioned that there was no water drop in the cloud. However, a mixed-phase cloud is probable in this temperature range. Fig. 3 shows that the temperature in the presence of cloud ranges from 0 to -40 C. Between -38 and 0 C, super-cooled water drops co-exist with ice particles (Rosenfeld and Woodley, 2000), and there is a great chance of water contamination. It is important to address this, and explain how you detect water drops and exclude them. Alternatively, is it possible to quantify the ratio of liquid water content to ice water content?

- There is no comparison between your retrieval and direct measurements of size spectra, because there was no in-situ measurement available for your case. It is true that disagreements exist between various in-situ probes (see also Fig. 6 in Cotton et al., 2010), but still it is not certain if your retrieved size spectra would be more accurate. It would be good to cite any study that compared retrieved size spectra with direct observations. In any case, such caveat (no comparison between your retrieval and in-situ measurements) should be explained in the manuscript, and should be mentioned in the abstract and conclusions.

- The Brown and Francis (1995) mass-size relation has an important issue: it's not realistic for size smaller than 100 microns, since it gives ice particle mass larger than that of a sphere. See Erfani and Mitchell (2016) and their Fig. 1. I understand that you do not detect particle smaller than 0.75 mm, but it is important to address this issue for the readers who might use Brown and Francis mass-size relation. In addition, the readers will become aware of the more recent mass-size relations.

- Your radar is unable to detect particles smaller than 0.75 mm. This means that your retrieved data is not able to approximate the vast majority of particle number density or dN/dD (because small particles dominate the number concentration or N; again see Fig. 6 in Cotton et al., 2010). How does that affect your calculations? Since the calculation of number concentration is an important part of your paper, you should highlight this limitation (no detection for size less than 0.75 mm) and its consequences in the abstract and conclusions.

Specific comments:

- abstract, ln 5: Did you calculate the mean size change by aggregation?

- abstract, ln 11: Any evidence to support this? I understand that this is suggested based on previous studies. If yes, it should be mentioned explicitly: "Based on previous study, we suggest ..."

- pg 2, ln 7: By "cloud microphysical properties", do you mean individual ice particle properties such particle size or mass?

- pg 2, ln 14: Please add at least one example (with a reference) on how different size spectra affect the relative importance of microphysical processes.

- pg 2, ln 15: Please add a reference.

- pg 2, last paragraph: It is good to cite Keith and Saunders (1989), since they performed experiments and measured the aggregation efficiency for various shapes and sizes. They showed that the aggregation efficiency ranges between 0.3 and 0.85 for planar snow crystals depending on the particle size.

- pg 3, Section 2: Please add proper references for each radar and for the near-field correction method. Overall, this section doesn't have sufficient citations and I can see only 2 references in the whole section.

- pg 4, paragraph starting at ln 14: Have you tried to correct the direction of 2 radars and make a few measurements, and then compare with the previous measurements?

- Table 1: Right now, it is not mentioned anywhere in the manuscript.

- pg 5, ln 26: Are these temperatures measured by radiosonde?

- pg 5, ln 28, Change to "Figure 2b".

- pg 5, ln 30: Was the Westbrook model initialized for the same cloud?

- Fig. 2b an 2c: The explanation of Fig. 2b in the manuscript is not enough. What is the physical interpretation of such difference between the two radars. Also, the explanation of Fig. 2c is missing in the manuscript.

- Fig.3 and 4: You explained Fig. 4 in the manuscript earlier than Fig. 3, so please switch these figures.

- pg 6, ln 6: Briefly define the scattering model. Also, do you mean individual ice particle or a bulk property such as mean size or median size?

- pg 7, ln 2: See the general comment regarding mass-size relation. It would be good to cite Erfani and Mitchell (2016) since they explained recent mass-size relations.

- pg 7, ln 1-4: The steps 2 and 3 need to include the relationships you used to relate various variables.

- Fig. 4: When the x-axis says "particle diameter", do you mean the maximum size of each particle, or did you calculate the sphere-equivalent diameter? Moreover, the explanation of panels b-e-h is missing in the manuscript.

- pg 10, ln 15-16: When particle sizes grow, but their fall speed does not increases, this is a sign of branching and aggregation rather than riming. See Locatelli and Hobbs (1974).

- pg 10, ln 17-24: Combine all these lines into one paragraph.

- pg 10, ln 32: Doppler spectra is not bi-modal in Fig. 4a. Do you mean Fig. 4b?

- pg 10, ln 33: Why are such small particles a result of nucleation and not growth by vapor deposition, or a secondary ice production (such as fragmentation of ice particles)? Elsewhere you assumed the small particles in the bi-modal spectra are the result of vapor deposition. Any evidence on the mechanism responsible for the increase in small particles?

- pg 11, ln 1: You say the aggregation causes ice particles to grow larger and fall faster, but aggregate fall speed does not grow by size. See Locatelli and Hobbs (1974) and their Fig. 12. They also provide fall speed-size relations for various ice particle shapes (including dendrites and aggregates).It's good to cite this paper, and also it would be great if you fit their relation to your data and calculate the R-squared.

- pg 11, ln 3-4: This can be a sign of aggregation.

- pg 11, ln 11: This is an exponential function. Moreover, I assume D and dN/dD are known in this equation. How did you calculate N0? It is important to explain this in the paper. It seems that the value of slope is dependent on the calculation of N0. Furthermore, do you use such distribution to relate size to radar reflectivity? Your size spectra do not include small particles. Since the number of small particles contributes significantly to the number concentration, how did this affect your calculations?

- pg 11, ln 13: This is a qualitative comparison. Have you looked at the difference between Fig. 5a and 5b? From Fig. 5c, it seems the agreement between the 2 slopes is not excellent. Note that this is a logarithmic axis and I can see the red line can be larger by a factor of 1.5.

- pg 12, ln 10-12: How did you calculate F (ventilation coefficient) and K (thermal conductivity)?

- pg 12, ln 26-27: The vapor deposition and riming do not change the total number of ice particles (N), but they do change the number of ice particles within each size bin (dN/dD). Please clarify that the rate of change in size is not the same for all sizes. As an example for riming: riming collision efficiency is a strong function of ice particle size, so larger ice particles would grow faster due to riming. See Wang and Ji (2000) and their Fig. 7; might be good to cite this paper.

- pg 12, ln 27-28: Please refer to the proper equation number in Mitchell (1988).

- pg 14, last paragraph: This statement is suited for the Introduction and can be moved

near the end of Introduction as the motivation for your study.

- pg 15, first paragraph: See my general comments on the lack of comparison with in-situ measurements; I agree the issues exists in directly measuring the particle size and concentration, but still it is unclear how your method has better accuracy. In addition, please cite Cotton et al. (2010) when explaining the disagreements in the in-situ measurements of ice particles.

References:

Cotton, R., Osborne, S., Ulanowski, Z., Hirst, E., Kaye, P. H., & Greenaway, R. S. (2010). The ability of the Small Ice Detector (SID-2) to characterize cloud particle and aerosol morphologies obtained during flights of the FAAM BAe-146 research aircraft. Journal of Atmospheric and Oceanic Technology, 27(2), 290-303, https://doi.org/10.1175/2009JTECHA1282.1.

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Rosenfeld, D. and Woodley, W. L. (2000). Deep convective clouds with sustained supercooled liquid water down to -37.5 C, Nature, 405, 440–442, doi:10.1038/35013030.

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