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Atmospheric Measurement Techniques Discussions

Interactive comment on "Establishment and preliminary application of forward modeling method for Doppler spectral density of ice particles" *by* H. Ding and L. Liu

Anonymous Referee #1

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The authors present a forward modelling approach for six different ice particle types, with a particular focus on the Doppler radar spectral density. Starting from six different, literature-based particle descriptions of mass-, area- and velocity-size relationships and by using self-similar Rayleigh-Gans approximation to determine the backscattering cross section of the particles they build a forward model for each particle size and type. This is initially used in combination with an assumed particle size distribution (inverse exponential) to evaluate the relative differences in the forward-modelled Doppler radar spectral density for the different particle types. Later this method is inverted using radar observations to estimate the particle size distribtuion in clouds observed over China, which are additionally evaluated against aircraft-based measurements of the

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particle size distribtion. The retrieved particle size distribtuions (one for each particle type) show an uncertainty of around one order of magnitude, but are consistent with the aircraft-measured particle size distribution.

In general I find both the paper and the results presented interesting. However, in several parts I found the description of the method either confusing or incomplete. The figures are generally well chosen and clear, although some can be improved (see below). The method applied seems reasonable (although without further clarification of exactly what was done, I cannot be sure) and the agreement of the retrieved size distribution with aircraft observations is encouraging. The authors acknowledge that this is a "preliminary attempt" to develop the forward model and the results to this look point look interesting. After addressing the clarity issues below, this work could contribute helpfully to the scientific literature in this field.

Main concerns: 1. Not enough clarity and information in the description of the method - there are numerous sections (which I list individually below; points 4-8) where the paper is hard to follow. In particular, I am still unclear how the particle size distribution was retrieved from the radar observations. The only reference I can find in the paper says "We ... used the microphysical relations established in Section 3 to derive the PSD", but how exactly remains unspecified. Overall there is insufficient description to understand the method and/or to reproduce it.

2. The work nicely evaluates the difference between the forward-modelled PSDs for different particle types. However, for the retrieval of a PSD from the observed radar data some prior knowledge of the particle type/shape would be required. In this paper, the authors calculate six different size distributions - one for each particle type. Although the size distributions agree relatively well with aircraft measurements, there is an approximately order-of-magnitude difference in the absolute number concentration at different sizes. The authors do not explain how to overcome this need for a-priori information about particle type. Overcoming this issue would be required to perform the long-term statistical analysis they propose in the conclusions. Therefore I see difficulty

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in finding real-world applicability of this work.

3. This is not the first attempt to determine ice cloud properties from Doppler spectral density data; however, the authors fail to detail the relative strengths and weaknesses of their method in relation to others already published. A discussion of how this work is similar or different to existing work (i.e. only one radar, but particle type is not known) is required in the introduction and/or later sections. Relevant references (and references therein):

for liquid: Kollias, P., Rémillard, J., Luke, E., and Szyrmer, W.: Cloud radar Doppler spectra in drizzling stratiform clouds: 1. Forward modeling and remote sensing applications, J. Geophys. Res.-Atmos., 116, D13201, https://doi.org/10.1029/2010JD015237, 2011

for ice: Barrett, A., Westbrook, C., Nicol, J., and Stein, T.: Rapid ice aggregation process revealed through triple-wavelength Doppler spectrum radar analysis, Atmos. Chem. Phys., 19, 5753–5769, 2019

Kneifel, S., Kollias, P., Battaglia, A., Leinonen, J., Maahn, M., Kalesse, H., & Tridon, F. (2016). First observations of triple-frequency radar Doppler spectra in snowfall: Interpretation and applications. Geophysical Research Letters, 43(5), 2225-2233.

Specific concerns: 4. page 9, line 224. Please state specifically which values of kurtosis and power-law prefactor used, or describe clearly which part of Hogan and Westbrook (2014) has been used (e.g. page/equation numbers)

5. page 11, line 256-268. From this paragraph is it unclear what is meant. One part says "the backscattering cross-sections are almost equal" (for the different particle types?), but later "it is crucial to choose shape parameters for ice particle types". I recommend rewriting this paragraph to clarify the intended meaning.

6. The largest problem I had with understanding related to the use of the PSDs. This is mostly covered in section 2.3.2 for the forward model. (The information for the inverse

retrieval is completely missing) However, the details are also mixed with a lot of other content which made finding the relevant details difficult.

line 280 - please additionally define S_Z and V_f here.

line 284 - What do you mean by the "average PSD was used"

line 286 - how have you used a range of D_e values (307-989)?

line 288 - initially the 35 dB range of reflectivity for the same particle size distribution was very confusing

line 291 - the reflectivity bias of 9.25 dB - is the difference explained by different masses or densities of the particles?

line 291 - what is assumed about the particle orientation during these calculations?

Figure 4 - the use of "...of single crystals" in the figure labels is very confusing (I was thinking: what is the size distribution of a single crystal?) and should be removed. I think you mean "of the different particle types" - but this would be clear from the figure legend and therefore does not need to be included on the figure axes.

line 296 - how have you determined the "Doppler spectral density width" - is this different from the "Doppler spectral density" mentioned previously?

line 310 - "it has the biggest" - what do you mean by "it"?

line 315-319 - please rewrite the entire sentence.

line 319 - what is "Doppler spectrum intensity magnitude"? please define

line 321 - I suggest adding a paragraph here describing what you are attempting in the upcoming paragraph. As of now, I do not understand how (or why) you are attempting to use the Doppler spectra of stellar plates, combined with the doppler spectra of aggregates of columns to derive the PSD of four other particle types - when earlier it was stated that the PSD from Figure 4a was used for all particle types.

line 327 - Further confusion comes when you state that "the retrieved PSDs ... are obviously larger than the original one". What do you mean by the "original one" here?

line 321-334 - The whole paragraph is complicated to follow and difficult to relate to figure 5. I suggest rewriting.

7. Section 3

line 346 - I suggest breaking the paragraph here, so that mode detail can be added about how the radar data and the inverted Doppler spectrum was used to determine the particle size distribution from the MMCR data. The text from line 346-352 is insufficient to explain what is the main benefit of your work. Additionally, the reference to section 3 (line 350) is incorrect, because the current section is section 3.

line 351 - what is the meaning of the "particle physical scale" in this sentence?

figure 6, caption - how did you determine the vertical air speed. This information needs to be added to the text. line 360 & 362 - what is the "PSD spectral width"? How is it defined and calculated?

8. A small table containing often-used symbols (De, Sz, Ze, sigma, etc.) would be useful

Minor comments:

9. line 33 - reference Liou (1986) incorrectly formatted

10. line 36 - please add a supporting reference for "most precipitation in China is related to theice phase process"

11. line 52 - "particle sizes are easier to calculate for liquid particles..." (+than for ice particles)

12. throughout paper - inconsistent use of "SZ" and "S_z" (with subscript). Similarly for Dm, De and D_m, D_e (with subscript)

13. line 140 - MAGANO and Chung (1996) - correct capitalisation

14. line 172 - "calculation methods of calculation"

15. line 212 - Hogan et al. reference missing year - and missing from reference list

16. line 226 - "different ice particles types of ice particles"

17. line 255 - single sentence paragraph

18. line 285 - "Doppler (+spectral) density"

19. figure 4b - I suggest a different line style for aggregates - as they use a different set of axes

20. line 324 - "coordinate axes" –> "ordinate axes"

21. line 340 - define "MMCR"

22. line 340/figure 6a - velocity should be unfolded for the example plot

23. line 347 - "inversed" –> "inverted"

24. figure 6 - suggest using same height axes (0-10 km) for both sub-panels. Also label the y-axis "Height" in both.

25. figure 7 - units of mm6 s m-4 are incorrect here

26. lines 411-415 - the averaging range appears to be in the melting level. This must affect the averaged quantities for the final analysis. A comment about this, or a choice of different height range is suggested.

27. line 426 & line 492 - I strongly disagree that rapid microphysical changes are required to produce precipitation. Precipitation could occur from a quasi steady state atmosphere. Without seeing the full time-height plot from the radar, I cannot determine whether the atmosphere really did vary rapidly during this time window - but I don't believe that this statement is justified.

28. figure 10 - suggest using same height axes (0-5 km) for both sub-panels. Also label the y-axis "Height" in both.

29. figure 10 caption - define "HVPS"

30. line 443 - is it possible to estimate how much LWC might have been missed because of the small particle problem?

31. line 446 - aliasing of what, where and how? Why is it relevant? Do you mean figure 6a, rather than 7a?

32. table 3 - what are the input and output units for IWC, Z_e the equations given?

33. line 479-485 - conclusion point 2 is confusing

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