Atmospheric Measurement Techniques Discussions

Atmos. Meas. Tech. Discuss., referee comment RC1
https://doi.org/10.5194/amt-2021-168-RC1, 2021
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Comment on amt-2021-168

Anonymous Referee #1

Referee comment on "Retrieving microphysical properties of concurrent pristine ice and snow using polarimetric radar observations" by Nicholas J. Kedzuf et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2021-168-RC1, 2021

Review of "Retrieving microphysical properties of concurrent pristine ice and snow using polarimetric radar observations" by N. J. Kedzuf, J. Christine Chiu, Venkatachalam Chandrasekar, Sounak Biswas, Shashank S. Joshil, Yinghui Lu, Peter Jan van Leeuwen, Christopher Westbrook, Yann Blanchard, and Sebastian O'Shea.

Summary: This paper presents a framework for estimating the bulk properties of pristine and aggregated ice particles from polarimetric radar measurements. The framework consists of an interative ensemble algorithm to estimate the distribution of particle size distribution (PSD) parameters by informing a prior distribution with radar measurements. The radar measurements are simulated from the PSD parameters using scattering database results for several types of ice particles. The retrieval method is first tested in a known truth experiment, with retrieved parameters that agree with the true parameters. Observed radar data are then used to demonstrate the retrieval, and in situ aircraft measurements are used for validation on a number of radar gates. The results improve upon previous empirical retrieval methods for ice number concentration and ice water content, however, retrievals of the effective mean diameter are less accurate.

General comments:

I find this paper to be well written overall and I think it should advance the use of radar measurements to understand ice precipitation. I especially appreciate that the method presented in the manuscript provides uncertainty estimates for the retrieved quantities and the authors do a nice job incorporating the retrieval uncertainty into their analysis. I do have a few general comments and several specific comments that should be addressed, and therefore I find this manuscript acceptable for publication subject to minor revisions.

I have some concerns with the collocation of the in situ aircraft measurements and the radar data. It is perhaps reasonable to have a relatively large acceptable horizontal distance between the aircraft and the radar measurements, subject to the condition that the precipitation is horizontally homogeneous. However, discrepancies in the vertical positions of these measurements are less acceptable. Within a layer favorable for planar crystal growth and subsequent aggregation, there will typically be large vertical gradients in the radar measurements; these gradients reflect the rapid growth via vapor deposition and large changes in the bulk particle properties (e.g., mean diameter) via aggregation.

Given these large gradients, measurements offset vertically from eachother can represent substantially different ice particle populations. The authors need to address this collocation threshold by reducing the acceptable vertical difference between the in situ and radar measurements. Without knowing the relative locations of these observation sources, it is difficult to draw conclusions about why the retrieved effective diameters do not agree with the measurements.

Additionally, some of the details in the ensemble algorithm are unclear and I think require a bit more explanation to understand the algorithm and contextualize its results. For example, is there an assumed form for the prior and posterior (e.g., Gaussian), and are the state vector elements assumed to be independent in the prior? Do these assumptions about the prior probability distribution impacts the retrieval results?

Finally, there should be more discussion regarding the applicability of the retrieval method in various ice growth regimes. The authors do mention using the framework to study secondary ice nucleation; however, it is unclear whether this application would require also considering rimed particles. In general, rimed particles, aggregates, and pristine ice crystals of different habits can all exist in the same radar sample volume. This manuscript would benefit from a more thorough discussion about the current capabilities to handle these more complex situations and/or future plans to implement them.

Specific comments:

- Line 45-48: This sentence needs to be revised to more clearly motivate why understanding the relative proportions of aggregates and pristine ice crystals is important in understanding cloud and precipitation processes.
- Lines 76-77: It is important to note here that aggregates have an infinite variety of complex shapes. Characterizing them as having "spheroidal morphologies" is incorrect, and stating that Z_{DR} is low because particles are spheroids is also incorrect because highly oriented, high-density spheroids can have high Z_{DR}. Please rework this explanation for the assumed Z_{DR} of aggregates.
- Line 86: What do you mean by the statement that Rho_{hv} and K_{DP} are "more advanced" measurements? Please be more specific.
- Lines 106-107: The size distribution must include the differential size (i.e., dD) in order to represent the number concentration of particles within the differential size range about D. Please modify.
- Lines 114-122: It's a bit unclear whether there are separate PSDs for the aggregates and pristine ice crystals since the equations here are written in terms of a single PSD (n(D)), but later in the manuscript N_0 and D_0 are retrieved for both aggregates and pristine ice crystals. Please clarify in this section.
- Lines 145-150: Clarify whether the state vector is updated independently at each range gate. In other words, do radar observations at one range gate influence the estimation of the state vector at another gate?
- Line 152: Are there values of K_{DP} less than or equal to zero? If so, how are they handled when logarithms of these values are taken to create the observation vector?
- Lines 180-181: The aggregates in the Lu et al. (2016) database have somewhat limited shapes since the monomers they are composed of are either single-width (in terms of a single GMM sphere) columns or stellar crystals with single-width branches. The authors should add some note here that natural aggregates may have substantially different properties for a given size compared to these simplified particles.
- Line 196-197: Add a reference to support this statement.
- Lines 200-201: Clarify whether this mass-size relation corresponds to a pristine particle or an aggregate of pristine particles.
- Line 209: I do not see clear evidence of individual dendrites in Fig. 1c. It is more

plausible that aggregates of dendrites present. Please update the figure caption to more precisely describe the particle types that can be inferred from that image.

- Line 214: How are the axis ratios defined? Are they determined by fitting an ellipsoid to the aggregate shape? Please elaborate.
- Line 233: There is seemingly a contradiction here between stating that the variables other than N_{0p}"lack a clear dependence on height" and line 242 where the slopes of D_{0P} and D_{0A} are assumed to be negative. Please clarify.
- Lines 236-237: Please add some explanation for why you added noise in this way to the prior.
- Lines 243-244: Please clarify where the two order of magnitude range in the state variable prior comes from (i.e., is that comparing ensemble members over the entire vertical profile or at a specific range gate). It doesn't seem to correspond to the standard deviation values listed in the table, especially for the N_{0A} and N_{0A}.
- Lines 285-287: The second sentence of this bullet point is incomplete. Please revise.
- Lines 312-315: Clarify whether the HVPS particle size distribution measurements are defined in terms of maximum diameter or volume-equivalent diameter (i.e., are they consistent with the PSDs used in the retrieval).
- Line 316: Does "simultaneous evaluations" mean comparisons for the D_{eff}, IWC, and total ice number concentration? Please clarify.
- Line 321: There is no Ryzhkov and ZrniÄ□ (2019) in the references; I think the authors are referring to the book "Radar polarimetry for weather observations" by Ryzhkov and ZrniÄ□ (2019)?. Please check that all the in-text citations match the reference list.
- Lines 366-367: These compensating effects are suggested because the estimated N_{0A} is higher than the true N_{0A} and the estimated D_{0A} is lower than the true D_{0A} . Can you show a scatter plot of these retrieved parameters from the ensemble? An inverse relation between these parameters would more clearly demonstrate the compensation effect to satisfy reflectivity.
- Line 399: Give the range of temperatures within this region rather than a single temperature.
- Lines 403-404: Isn't the habit predetermined before running the retrieval? The latter half of this sentence makes it seem like the retrieval is providing habit information independently. Please rephrase.
- Line 442: These spatial thresholds seem too large in cases where the precipitation is less homogeneous than what is observed in the RHI for the previous case (Fig. 6). I think the vertical distance threshold is especially problematic since the radar variables and associated ice particle properties can change substantially over 1 km (e.g., the observed and retrieved microphysical variables shown in Fig. 8).
- Lines 445-448: Are there general reasons why ~20% retrievals for these rays failed to reproduce the observed radar variables? There should be some discussion of this point to illustrate conditions where the retrieval assumptions are not satisfied.
- Lines 459-461: This section requires a bit more explanation. Does assuming plates are the pristine category in the retrieval provide a better correspondence between the measured and forward-simulated radar variables for all of the in situ measurements or just the ones where dendrites are observed? Also, how are the dominant pristine habits determined from the imagery?
- Lines 509-510: How well collocated were the radar gates and the aircraft during these times? If the measurements are sampling regions of precipitation with different microphysical processes, of course the retrieval will not agree with the in situ measurements.
- Lines 518-519: Reflectivity also provides information about the pristine properties, especially in cases where vapor deposition dominates and aggregation is limited. Please rephrase.
- Line 555: Add reference here for these equations.