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Atmospheric Measurement Techniques Discussions

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Interactive comment on "Synergistic radar and radiometer retrievals of ice hydrometeors" *by* Simon Pfreundschuh et al.

Anonymous Referee #1

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Summary of manuscript:

This is a conceptual study evaluating the ability of passive microwave and sum-mm measurements to complement radar reflectivity profiles to synergistically constrain profiles of ice particle size and concentration. An optimal estimation framework is applied to the problem in radiometer-only, radar-only, and combined radar-radiometer mode. The primary finding is that the measurements do indeed complement each other and the combined retrievals are less biased and have smaller errors than the radiometer-only or radar-only retrievals with respect to several parameters (mean ice particle size, number concentration, and cloud liquid water content). Sensitivity tests to the particle scattering model assumed in the retrieval forward model are also described in detail.

Summary of Review:

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Discussion paper

Overall, this study is quite thorough in several aspects: the description of the forward model assumptions are clearly stated, sufficient information is provided about the parameterization of the state vector to contextualize the optimal estimation results, and the retrieval of many parameters is analyzed in detail. The largest issue I find with respect to the methodology is the characterization of the measurement and state vector error covariance matrices. I suspect that this has lead to some ambiguous or sub-optimal (for the setup used by the authors) results, but I don't believe the general conclusions would be substantially affected by a more realistic treatment. Therefore, my disposition is for minor revisions (see specific comments).

General Comments:

1. As noted in Section 4.2.4, the a priori assumptions do not describe reality very well. In particular, I suspect that the information content of Dm and N0* is highly dependent on the a priori assumptions of these two variables in the retrieval framework. Especially with a radar measurement, since Z is sensitive to both parameters over a wide range of the parameter space, the relative sensitivity and therefore information content will almost entirely depend on the relative constraints on these parameters imposed by Xa and Sa. As such it is imperative to accurately characterize these. I understand the choice to use the DARDAR constraints, but it's clear from the cross-section plots that the model ice particle concentrations vary over a much wider range than the roughly 2 orders of magnitude that Eq. 4 provides over a 220-272 K temperature range. So, when the retrieval results are compared to model "reality", it seems that a lot of N0* variability is folded into Dm and this is especially evident in Figures 13 and 14. My overall concern is that it is difficult to interpret some of the results when the model fields and the a priori assumptions differ so strongly.

2. Forward model error is introduced when the different species present in the model microphysics are combined into one species and when different scattering models are used to represent the ice particles. That this is not represented in Se could lead to over-fitting and poor convergence (I suspect this is part of the reason why the normal-

ized cost is much higher for the radiometer-including retrievals). It should be relatively easy to quantify this error by re-running the simulations with the retrieval assumptions (combining ice species, different scattering models), and I suspect that this error term would dominate the instrument noise term for many channels.

Specific Comments:

1. Lines 85-88: I recommend the use of geographical spatial references (i.e., north/south rather than left/right)

2. Line 98 (also 176,252,449): Instead of vertical/horizontal (which are dependent one the convention used for plotting), I recommend the use of concentration/size to characterize the dimensions of the particle size distribution.

3. Line 100: A few more details on the Milbrant and Yau microphysics sheme that are relevant to this study would be helpful here. For example: What is the assumed shape (functional form) of the particle size distribution, and what are the prognostic variables (e.g., number concentration, mixing ratio)?

4. Line 135: Does the ARTS radar solver also provide analytic Jacobians?

5. Line 187: “particles” should be “particle”

6. Line 198: Is Dm also only retrieved at these 10 points, or just N0* (and Dm retrieved in each radar range gate as in Grecu et al. 2016)?

7. Line 256: Actually, this is only one example of how the radar and radiometer measurements can be complementary. Even if the lines were parallel (and thus no information distinguishing size from concentration could be obtained), the radar still locates the cloud and describes its vertical structure. One can imagine a cloud of the same ice water path and particle size at two different heights having different brightness temperatures due to changes in the water vapor absorption above the cloud – having the radar information would provide increased information content about the ice water path in this case than the radiometer measurement alone.

8. Table 4: Why are the values for GemSnow and GemGraupel different than in Table 1?

9. Figures 7 and 8: I'm not sure why these are separate figures – it seems like all panels could fit on one page.

10. Figure 10 is missing from the manuscript.

11. Line 374: recommend using "represent" instead of "predict"

12. Line 382: should be "reference" instead of "references"

13. Line 414: How are the truncated PSDs (using GemSnow) represented in the forward simulations? Is total ice water content conserved? If so, how is it spread among the valid particle sizes – equally, or is the truncated mass allocated to the smallest size bin?

14. Figure 16: The figure labels/captions aren't clear if they refer to total liquid water content/path or just the cloud liquid water/path.

15. Line 518: It's interesting that the Plate Aggregate provides the most accurate retrieval results, even though it isn't similar to the models used in the synthetic measurement simulations. Does the decreasing density with size better replicate the combination of high-density GemCloudIce (which tends to be present in high concentrations at small sizes) and lower-density GemSnow (which tends to be dominant at larger sizes)?

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