Title: Snow Microphysical Retrieval from the NASA D3R Radar During ICE-POP 2018

Manuscript summary:

The manuscript introduces an algorithm retrieving the particle size distribution and various microphysical properties of snow from dual-wavelength dual-polarization radar via optimization estimation. These estimations include characteristic particle size, shape parameter of the size distribution, rime fraction, mean aspect ratio, orientation distribution and snowfall rate (volumetric and water equivalent). The results are verified with the ground instrument during ICE-POP 2018. Most of the comparisons indicate high biases but with high correlation coefficients.

The major concern of the algorithm is trying to estimate various parameters (Eq. 13, 9 parameters at each gate) at the same time, yet the information for retrieval is limited (EQ. 12, 5 measurements). The validation indicates high biases. The manuscript needs substantial revision. Major revision is recommended.

We thank the reviewer for their effort in reviewing this manuscript.

Major comments:

1. Considering the number of variables (nine) is higher than measurements (five), it's highly possible the final retrievals are mostly from the "background" value (e.g., Prior in Table 5). The manuscript did not compare the PPI (or RHI)simulated measurements from "Prior" and "last iteration". This is important to ensure the retrieval is not mostly from "background" term (2nd term of RHS in Eq. 11). Figure 4 is the only figure to show that the final simulated measurements from optimal estimation. Yet, a ray data is not convincing. Please do show the PPI or RHI simulated measurements for all of the experiments including Hu-only, DWR-only, Ku-pol and All-obs.

This is a good suggestion. We have added a comparison plot of reflectivity, differential reflectivity, dual-wavelength ratio, and differential phase to the manuscript, with a discussion of how faithfully these variables are simulated using each set of measurements.
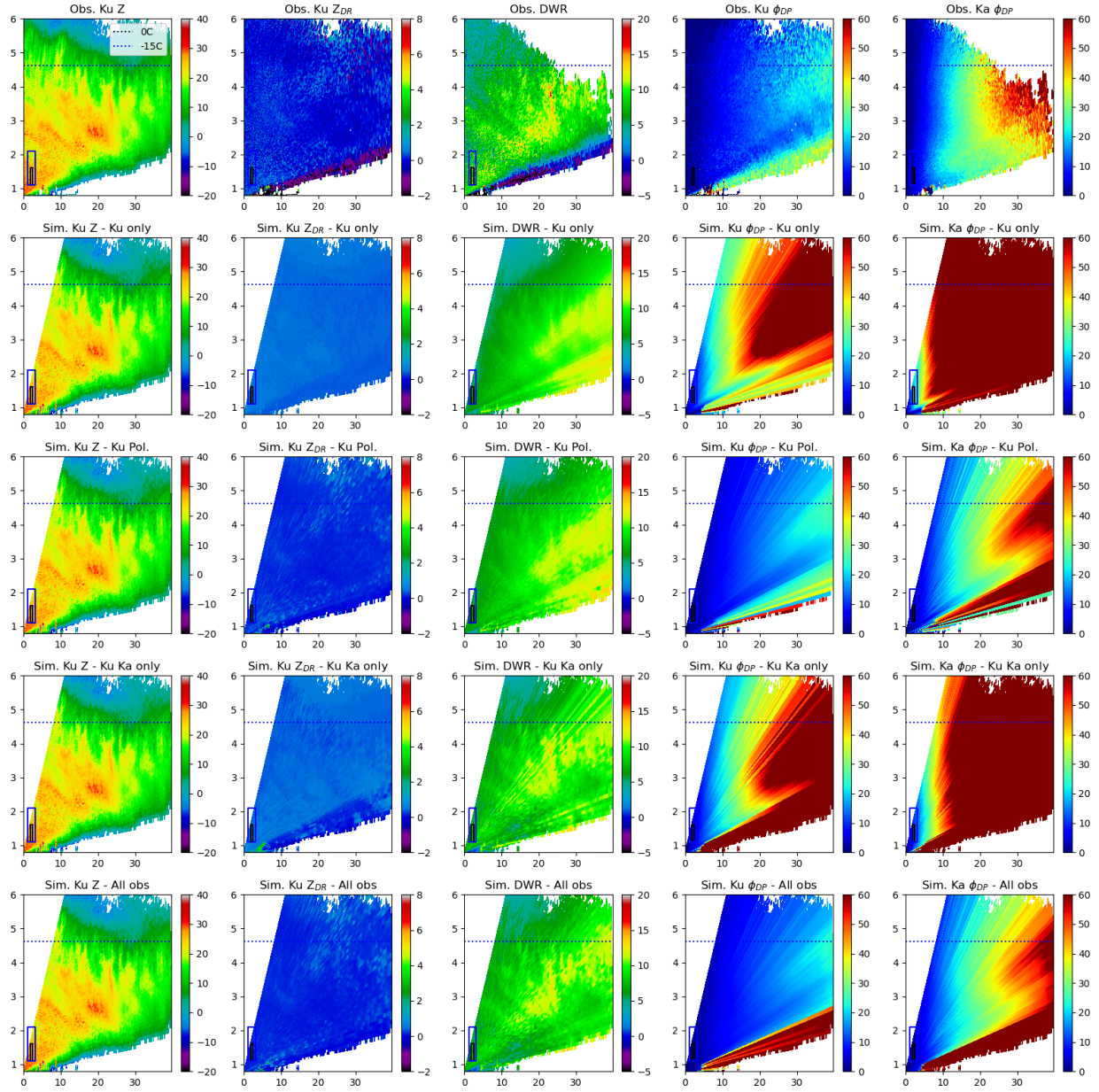
Figure R2: Comparisons of Ku-band Z (column 1; from left to right), Ku-band Z_{DR} (column 2), Ku-Ka Dual-wavelength ratio (column 3), Ku-band Φ_{dp} (column 4), and Ka-band Φ_{dp} (column 5). The top row are the observed values from an RHI taken at 13:00 UTC on 28 February at an azimuth of 231 degrees. Simulated measurements from the retrievals are shown for Ku-Z only (row 2), Ku-polarimetric (row 3), Ku-Z and Ka-Z only (row 4), and all observations (row 5).

We selected the RHI from 13 UTC on 28 Feb, since this was a timestep where the DWR calibration appeared to be reasonable, though perhaps still having some positive bias (see middle column of Fig. R1). The Ku-only algorithm (which essentially returns the a priori result) simulates Z_{DR} that is too high, DWR that is close to the observed values (but without some small-scale features), and Φ_{dp} that is too high at both frequencies. The Ku-pol

algorithm is able to match the polarimetric measurements (including the Ka-band K_{DP}, even though it is not an input to the Ku-pol algorithm, because the Ku-band and Ka-band K_{DP} are highly correlated), but still does not resolve the small-scale features observed in the DWR. The DWR-only algorithm is able to resolve these, but suffers from the same Z_{DR} and K_{DP} bias as the Ku-only results. The retrieval using all observations is best able to match these features, although for this case, it is clear that the polarimetric observations are providing the most information to adjust the microphysical parameters from their *a priori* values.

2. Since the observational information is limited, fixing the value of some parameters (e.g., axis-weighted ellipse ratio, riming fraction). Figure 10 and 11 indicate that the effective density and ellipse ration has little change compared to other variables. Has author considered to reduce retrieved variables?

This is a reasonable suggestion. The purpose of this study was to investigate sensitivities to all parameters, so we consider it a useful result to identify those parameters to which the measurements are not sensitive. So, we can fix these parameters to improve efficiency in future use of this algorithm.

3. Three cases are show for validation. Two of the cases (9 Jan. and 28 Feb.) has pronounced bias between radar measurement and PIP simulation (Fig. 8). Later, the retrieval bias can also be noticed among those two cases (Figs. 9 and 10). In terms of snowfall rate, author can consider perform more comprehensive validation by including more Pluvio data.

There are certainly errors in the PIP-retrieved quantities stemming from uncertainties in the microphysical assumptions of particle shape, fall behavior, etc. Comparisons between the observed and simulated PIP quantities do provide some useful ways of evaluating the shape and particle property retrievals purely from radar measurements. These results do show discrepancies between the radar-based retrievals of snowfall rate and particle shape compared to those derived from the PIP.. We have made our explanation for why these discrepancies occur clearer to the reader. Additionally, Pluvio measures accumulation quite accurately but does not have the temporal resolution necessary to validate rate on short timescales. It is used primarily as a tool to understand biases in the PIP estimation method.

4. Overall, the validation is rather disappointing. The bias and MAR are around +/- 30% in snowfall rate, nearly 40% in volume-weighted diameter (Dp), 40% in area-weighted ellipse and box aspect ratio. It's a good sign that the correlation coefficient is high. Moreover, there is no PPI or RHI retrieval to ensure that the retrievals are consistent in spatial domain.

We have added comparisons of the simulated and observed RHIs for one case (in response to the prior comment). Some of the discrepancy between the simulated and PIP-derived

particle properties is due to the natural presence of irregular ice particles that we don't incorporate into the retrievals. Owing to the PIP location being downradial of the D3R, the validation radar gates are 250-750m above the PIP. Therefore, some bias is to be expected when the ice particles continue to undergo microphysical growth processes as they fall towards the ground, as shown by substantial vertical gradients in the polarimetric radar variables during the 9 Jan case (see Fig. R1). Additional, some radar calibration errors produce biases in the reflectivity and/or DWR that can in turn bias the retrievals. We agree that the high correlation coefficient is a good sign, since it indicates a response of the radar observations to the parameters the PIP is measuring, but that there is a bias in either the forward model (i.e., our selected particle scattering properties), the radar observations, or both. These sources of error in the validation are further discussed in the revised section 5.

Minor comments:
Figure 4, please change the color of simulated measurements of the last iteration to red color for clarity.

Thanks for this suggestion, we have made the change to increase clarity.

Figure 9, please show the snow fall rate from "background" simulation.

The Ku-only retrieval (blue line) can be considered the "background" simulation, since it only uses the Ku-band Z_{HH} measurements and the *a priori* microphysics assumptions to retrieve the PSDs along the ray. This can be thought of as a single Z-S relationship (with attenuation correction applied).