Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2020-216-AC2, 2020

Atmospheric Measurement Techniques Discussions
Open Access
EGU

AMTD

Interactive comment

Interactive comment on "What millimeter-wavelength radar reflectivity reveals about snowfall: An information-centric analysis" *by* Norman B. Wood and Tristan S. L'Ecuyer

Norman B. Wood and Tristan S. L'Ecuyer

norman.wood@ssec.wisc.edu

Received and published: 24 September 2020

Dear Dr. Maahn,

Thank you very much, we appreciate your comments and suggestions. Our responses to your general and specific comments are as follows:

Responses to general comments:

1. Yes, with the exception that the retrieval here operates on single-range-bin reflectivity observations (and for this analysis involves no treatments for attenuation, multiple scattering or spatial correlation), this is the retrieval method used for CloudSat's 2C-

Printer-friendly version

Discussion paper

SNOW-PROFILE. A companion paper is near completion - it extends this retrieval to CloudSat Cloud Profiling Radar observations. We have added a statement indicating the relationship to the CloudSat retrieval in the introduction at line 74.

2. Yes, we've prepared a figure that shows the temperature dependence of the Z-S results obtained for this retrieval and makes comparisons of our results against a number of published Z-S relationships. It is included as Figure 7 in section 4 of the revised manuscript. Our results are consistent with several of these relationships at reflectivities up to about 5-7 dBZe. Above 7 dBZe, our results tend toward smaller snowfall values than a purely linear relationship would produce. The smaller values are more consistent with the Kulie and Bennartz (2009) HA particle results, which represent an aggregate particle. For our results, snowfall rates at a given Z become larger generally with warming temperature.

Responses to specific comments:

L120: Yes, it is the current, iterative estimate of the a posteriori covariance of x, exactly. We have reworded the description to provide this information.

L120: Yes, This test is actually obtained from Marks and Rodgers (1993) from their equation (16) and the discussion that follows, but it is the implementation of the test for correct convergence described by Rodgers (2000) in section 12.3.2. We now also include a citation of Marks and Rodgers.

L169: Yes, the optical instruments do underestimate Dmax (see Wood et al., 2013, for example). The retrieval used in Wood et al. (2015) to determine the microphysical and scattering a priori properties used in this retrieval includes compensation for this effect. Accordingly, the a priori properties used in this retrieval are based on Dmax.

L174: Yes, much more so that would N0 itself. Please see the figure we've provided.

L204: Yes, although that opinion is based on tests done with the actual CloudSat retrieval product in comparisons against ground-based observations (primarily in Antarctica and Sweden).

Figure 1: The differences appear more substantial than what would be attributable to shattering (this is based on a quick look at the corrected versus uncorrected distributions in Field et al., 2006, JTECH). The aircraft data in Figure 1 include observations well above the surface. We expect that the differences are largely due to microphysical processing between locations aloft and the surface. Documentation for the C3VP aircraft 2D probe particle data do not indicate whether shattered particle correction was performed.

L228: Corrected, thank you.

L233: We agree, but we've revised this sentence somewhat differently than suggested. We indicate that both bias and measurement noise contribute to reflectivity errors, but that we've used the CPR noise characteristics to estimate S_y.

L247: This paragraph was revised to provide more details about K_b.

Figure 3: Done, the caption was changed to indicate that measurement uncertainty is shown.

L266: Another way to look at this question is to ask, given two different radar volumes filled with particles that follow exactly the same m(D), same Ap(D) and same size distribution but whose particle shapes are not constrained to match each other, does it seems reasonable that their reflectivities could differ by about 2 dB? That seems possible, but yes, may be conservative especially given that, for snowfall, we are often observing populations of irregular aggregates rather than pristine particles..

L281: There was no strong reason for not using Heysfield and Westbrook (2010) for fallspeeds. As part of other work (that is described in Wood et al., 2014, 2015), we performed tests by switching between HW2010 and Mitchell and Heymsfield (2005) and found little impact on those retrieval results, but we should revisit our choice for this retrieval.

L286: We have revised equation 19 slightly to clarify that S_{\tilde{b}} is the uncertainty in snowfall rate that results from the uncertainties in the particle model parameters, and added a description of how it is calculated.

Figure 8: We agree there would be value in comparing against other datasets, but this comparison does illustrate the effects of substantial departures from the a priori assumptions of the retrieval and the behavior of accumulation errors. We do plan to apply this retrieval method to other field experiment datasets that involve ground-based radars.

L345: We are examining the calculation of accumulations from intermittent observations (such as provided by CloudSat) and the resulting errors for the companion paper. We agree, it isn't clear that the treatment here for a fixed radar taking essentially continuous meausrements would be highly applicable to CloudSat.

L376: It's a bit of a numerical coincidence due to the particular values of H. The number of states is given by 2**H (described well in the L'Ecuyer et al., 2006 reference).

L378: Thanks very much for providing this information. In this single-bin reflectivity-only retrieval, the S_Epsilon matrix consists of a single element, so is never ill-conditioned. The other matrix that must be inverted and that is used in the A-matrix calculation is the a priori covariance, S_a; its condition number is around 20. The final matrix that must be inverted has condition numbers ranging from 35 to 95. These are somewhat large, but indicate a potential loss of precision of only 1-2 decimal places in the inverse calculation (which uses double-precision arithmetic). Based on these values, we think it seems less likely that ill-conditioning is the source of the negative A-matrix values.

Figure 12: This is an interesting interpretation. Yes, it seems it could be an indication that the retrieval is prevented from fully utilizing the information in the reflectivity observation. It would be interesting to try including m(D) parameters in the state vector, maybe using a Rayleigh regime reflectivity forward model, just as a test.

L450: Unfortunately, the effort by the GHRC to archive the C3VP observations (including those used in this study) was initiated as a result of this manuscript and is not complete. We are looking at alternate archive locations and will need to add the necessary information prior to the manuscript being accepted by AMT.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2020-216, 2020.

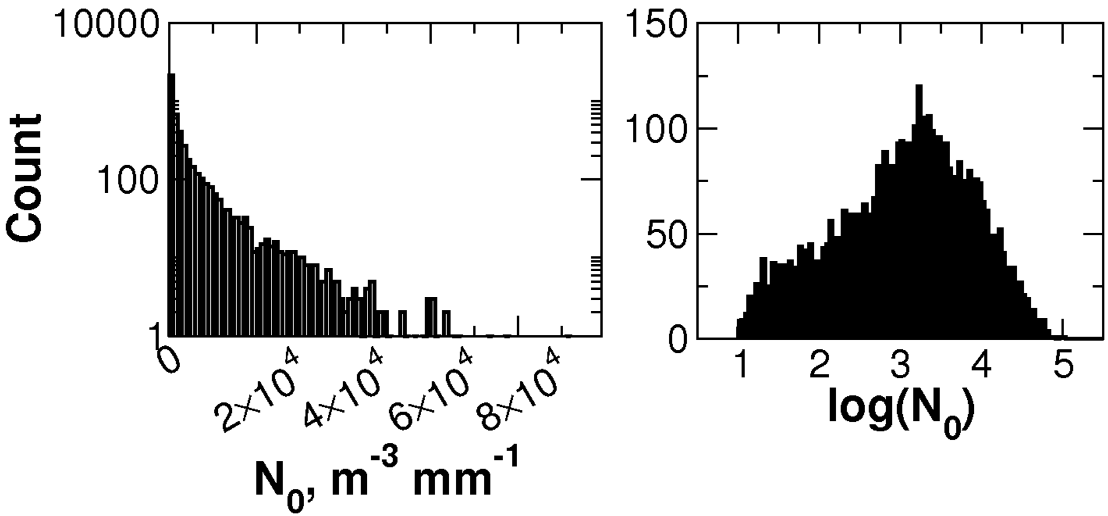

Fig. 1. Histograms of N0 and log(N0)