Riming-dependent Snowfall Rate and Ice Water Content Retrievals for W-band cloud radar

N. Maherndl, A. Battaglia, A. Kötsche, and M. Maahn

April 26, 2025

Original Referee comments are in italic

> manuscript text is indented, with added text underlined and ~~removed text crossed out.~~

We would like to thank the reviewer for their helpful comments. We revised the manuscript and responded to all of the reviewer's comments.

Reviewer I

Thank you for the answers to my comments.

"It must be noted that our reference IWC and SR data are not fully independent of Ze because we derive the particle mass from the retrieved normalized rime mass M . This is a necessary limitation because IWC and SR cannot be inferred from the available in situ measurements alone. For SR, we evaluate our approach with completely independent SR gauge measure"

I am fully aware that this is a necessary limitation. What I think would be good is to give the reader some discussion of the implications of this limitation.

For example, in the review answers, you mention: "If Ze would have a positive bias, then M would have a positive bias as well, resulting in a positive bias of IWC" That means in Fig. 4a, the data points would move towards higher Ze and IWC at the same time. Therefore, e.g. the slope of the fit in Fig. 4b would be unaffected?

Yes, we presume that the slope in Fig. 4b would not be affected by a positive bias in Ze. However, the exact relation (i.e. a positive bias of x dB results in a factor y higher IWC) depends on the PSD and can therefore not be given universally.

In the manuscript, we added:

> As discussed in Sect. 3.2, our reference IWC and SR are not fully independent of Z_e due to the dependence on M. If Z_e would have a positive bias, then M would have a positive bias as well, resulting in a positive bias of IWC or SR. The slope of the fits in Fig. 4b,d would therefore likely not be affected by a bias in Z_e.

Or, as another example: For a given Ze (e.g. 5 dBZ), the measurements in Fig. 4a show a nice correlation between M and IWC: all the yellow points lie at the lower edge of the point cloud, all the black points at the upper edge. But this pattern is a direct consequence of the underlying retrievals and the fact that M and IWC are derived from the same parameters. It is not something the data reveals to us, if I am correct.

Not only M, but also the PSD impacts Ze and IWC. Assuming a fixed PSD shape, the pattern is indeed a consequence of the underlying retrievals: for a given IWC, heavily rimed particles result in higher Ze than unrimed particles when using the riming-dependent scattering parameterization from Maherndl et al. (2023). However, variability in PSD shape (e.g., a heavily rimed particle population with many small, but few large particles vs. an unrimed particle population with few small and many large particles) results in variability in the pattern. We therefore do not fully agree with the statement that the pattern says nothing about the data.

In the manuscript, we added:

> PSD shape also affects the pattern in Fig. 4a,c. Assuming a fixed PSD, the spread in IWC-Z_e space due to riming is a direct result of the underlying riming-dependent paramterization (Maherndl et al., 2023). However, variability in (observed) PSDs results in variability in the pattern.

You also mention: "We currently don't have size resolved measurements of particle mass" As an outlook: If you would have such measurements, could this lead to different results or improvements in the relations? If this could be measured in the near or far future, would it be worth to repeat the study?

Size-resolved measurements of particle mass would lead to improvements by reducing uncertainties in the mass-size assumptions we make. Additionally, a completely independent in situ IWC could be derived, which would be a better reference IWC.

In the outlook, we added:

> Further observational studies focusing on particle mass and scattering behavior are needed to investigate these assumptions. Uncertainties due to the mass-size assumptions could be reduced if size-resolved particle mass observations were available in the future. This way, completely independent reference IWC and SR could be derived with which the study should be repeated.

I think openly discussing such points would in no way reduce the importance or validity of the results of this publication, but give the reader a more holistic and nuanced view on the topic.

Thank you for the comments, the point is well taken. We have added further discussion in regards to the implications of the study limitations (see comments above).

Technical Notes

For a very high density of points like in Fig. 4a, scatterplots are not the optimal choice. With so many overlapping points, the final color of the plot is basically determined by the order in which the points are plotted, as well as the rendering settings of the plotting framework. In this case, a 2D histogram, where the mean or median M value is calculated for all points in the same bin, would be more appropriate.

We agree that scatterplots are not optimal for a high density of points. However, a 2D histogram or a color mesh plot is also not ideal for the information we want to show. In Fig. 4a,c we aim to show two things: 1. the density of data points and 2. the dependency of IWC-Z and SR-Z on M. If we only want to show 1., a 2D histogram would definitely be better. If we only want to show 2., a binned plot like you suggest with the median or mean M colored would be best. We think to show both 1. and 2., a scatterplot with semi-transparent, colored markers is a good compromise. We think that increasing the number of plots or panels does not add much value in terms of additional information and makes the plot more complicated and harder to read at first glance. We therefore have not changed Fig. 4 (yet). However, given the subjectivity of the matter, we are not opposed to changing the plot. If requested by the editor, we will provide an updated plot with an additional panel to display 1. and 2. separately as 2D histograms (1. showing the data density and 2. showing the average M).