How well do triple-frequency radar signatures of simulated and observed melting snowflakes compare?

Ori Davide[1], **Stefan Kneifel**[1], José Dias Neto[1], Mario Mech[1]

[1]University of Cologne, Germany

1. Introduction

The melting of ice particles is known to produce distinctive radiative features at microwave frequencies such as the radar bright-band and increased signal attenuation. An accurate characterization of the scattering properties of melting ice particles is not only relevant for precipitation retrievals from space but also for utilizing the observational fingerprints e.g. for model evaluation.

While the number of available datasets for complex aggregates and rimed particles is rapidly increasing during recent years, the number of available scattering datasets for realistic melting particles is very limited (especially regarding the number of particle sizes, shapes, and melted fractions included). This is certainly connected to the high complexity of the melting process and the large computational cost of scattering simulations.

We used two recent scattering datasets of realistically shaped melting snowflakes to calculate triple frequency scattering signal from partially melted snowflakes using a simple melting layer model that assumes constant melted fraction for all particle sizes and compare with radar observations of the ML

2. Melting Model

Both datasets use an heuristic approach (figure 1) to simulate observed characteristics of the melted snowflakes.

- Ori et al. (2014) used a stochastic aggregation algorithm to generate snow aggregates of various sizes that follows an observed mass size relation (Brandes et al. 2007). The melting phase statistically favors the melting of the particle from the areas with the smallest curvature

- Johnson et al. (2016) different sizes are generated by linearly scaling (magnifying) the same shape, thus the m-D relation scales as D^3 (figure 2). The melting model advances from Ori (2014) by allowing water volumes to migrate to the inner parts of the aggregate, imitating the properties of water surface tens

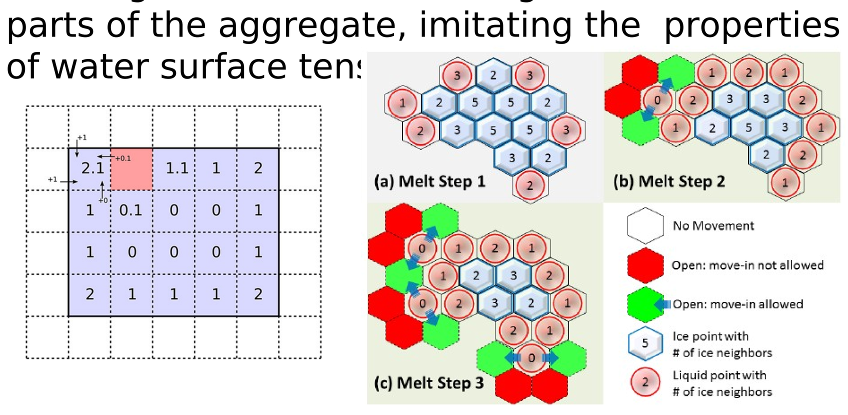

Figure 1: *Schematics of the melting model in Ori et al. 2014 (left) and Johnson et al. 2016 (right). In both models the chances for an ice volume to melt are a function of the numbers of neighboring ice, water and air volumes.*

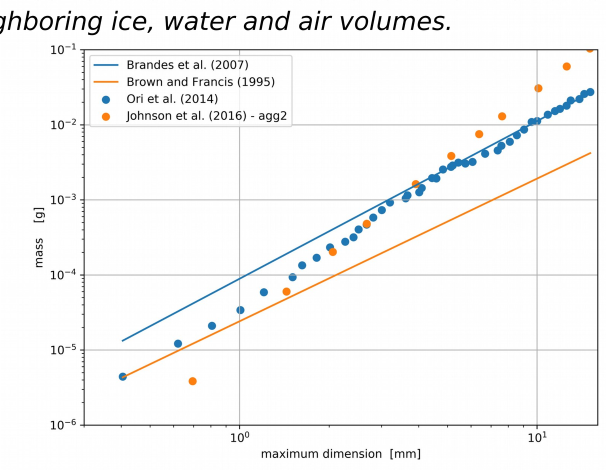

Figure 2: *Mass – Diameter relation of the modeled snowflakes. The power-law fits derived from two in-situ observations studies are plotted for reference*

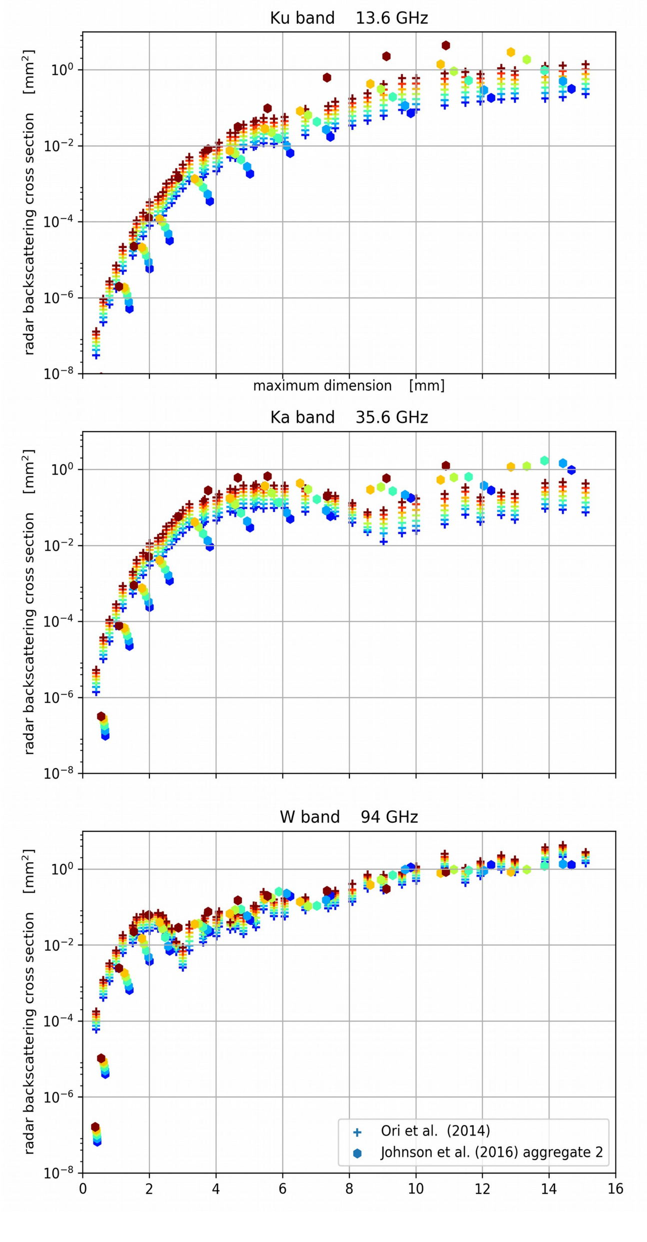

Figure 3: *Backscattering properties of the modeled melted snowflakes as a function of size and melted fraction*

The backscattering cross section (figure 3) increases with melted fraction. For BJ aggregate the simultaneous reduction of particle size partially compensate for the increased scattering of water. The scattering augmentation is larger at lower frequencies

3. Modeled triple frequency properties

We modeled the triple-frequency X (Ku for Johnson 2016), Ka and W properties by integrating the scattering properties over an inverse exponential PSD with different mean volume diameters D_0. We assume constant melting fraction over the whole PSD.

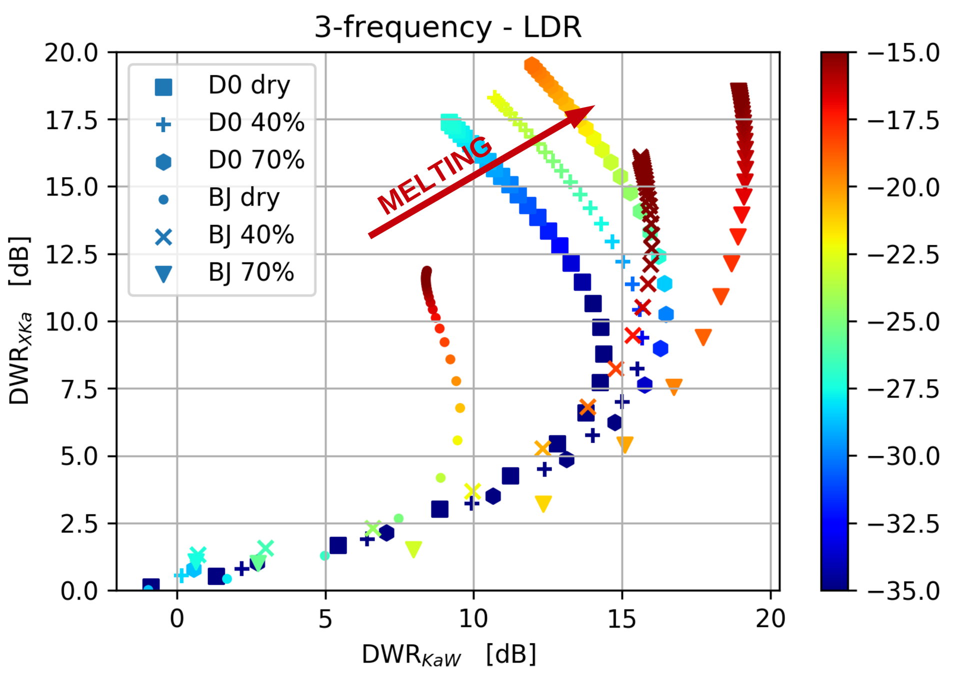

Figure 4: *Triple-frequency plot. X-Ka Dual Wavelength Ratio (DWR) as a function of the Ka-W DWR. Markers are color coded according to the LDR at Ka-band*

The predicted general effect of melting is to increase both DWRs and LDR (figure 4). BJ database produces "extreme" LDR signature: up to -15dB or 10 to 15 dB more than DO

Here D_0 is increasing along the curves

Assuming that aggregation dominates close to the melting layer, we use the mean volume size of the PSD D_0 as vertical coordinate (figure 5)

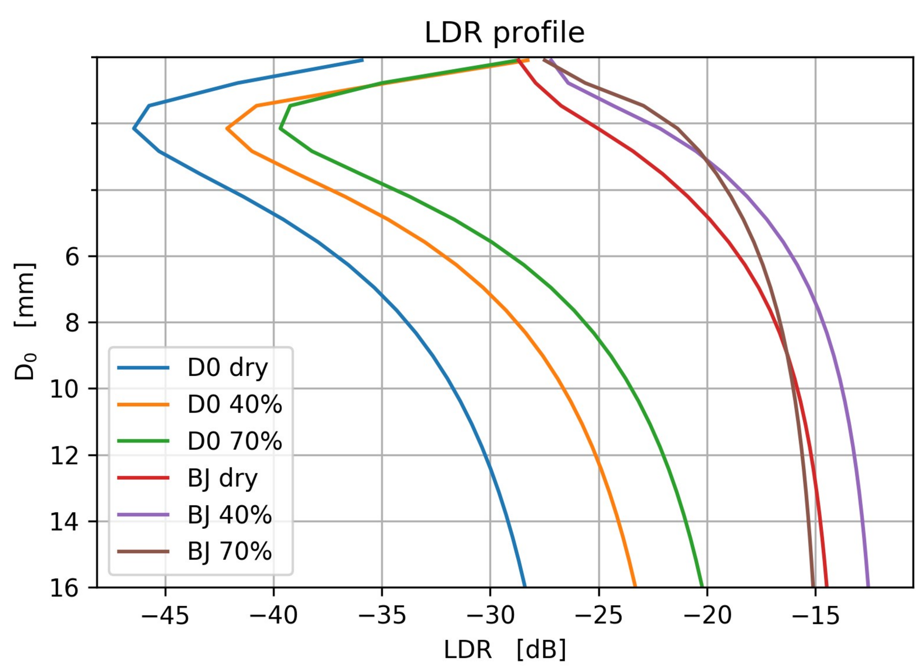

Figure 5: *Simulated vertical profiles of LDR using D_0 as vertical coordinate, for various scattering models and melted fractions*

Johnson et al. (2016) database simulates a monotonically increasing of LDR with PSD mean size. This is due to the constant shape of the particle which is simply scaled to get to the largers sizes.

Ori et al. (2014) simulates different particle for different sizes and shows a dip in the profile corresponding to the onset of aggregation. Smaller crystals are giving higher LDR due to their asymmetry.

Current modeling also does not take into account antenna crosspol isolation

By using LDR as an indicator of the melting stage we can better characterize the effect of melting on the triple-frequency scattering properties (figure 6)

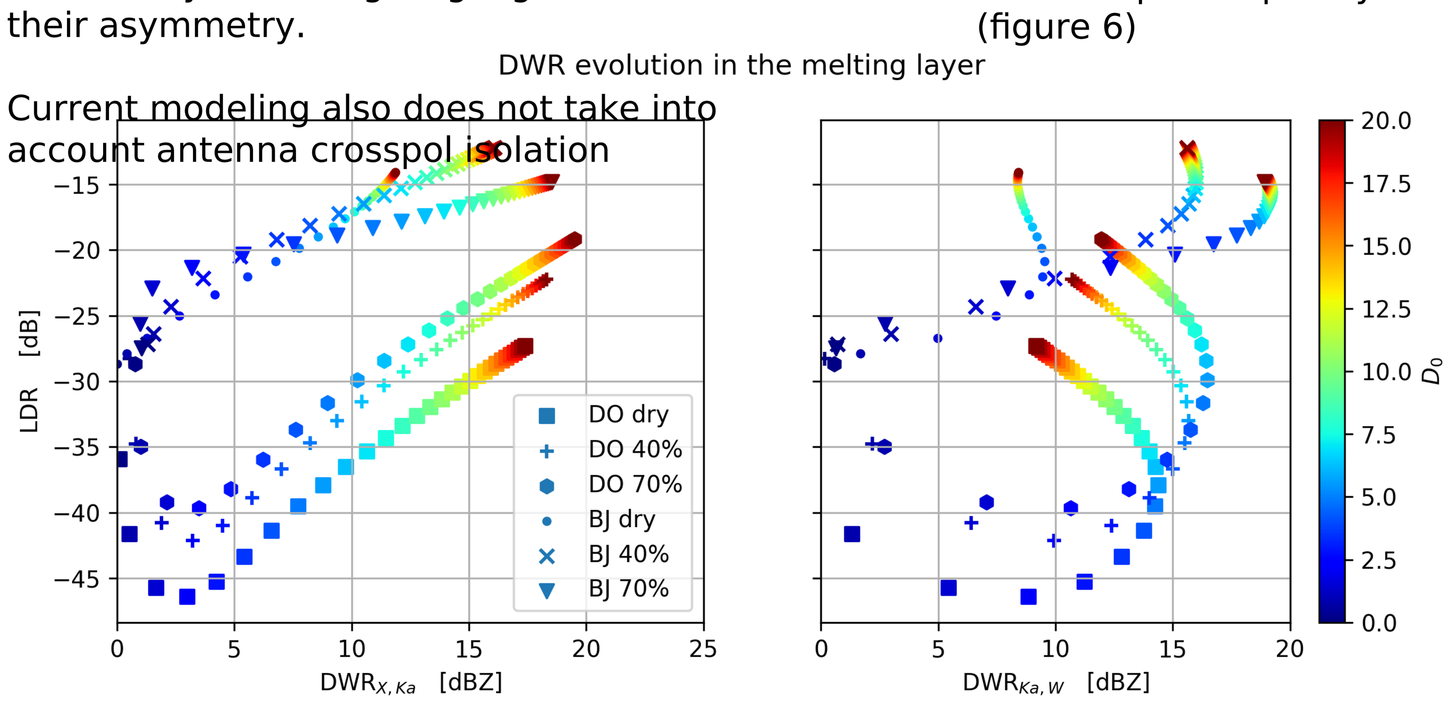

Figure 6: *Simulated LDR as a function of DWRs for various scattering models. Markers are color coded according to D_0.*

Conclusions

The scattering databases of melted snowflakes available so far are not able to fully reproduce the observed triple frequency characteristics in the melting layer.

General features and relation among observables can be reproduced, but the absolute values are affected by substantial biases.

The biases can be partially explained by the highly simplified melting layer model adopted (constant melted fraction) and more sophisticated assumption can be employed to evaluate the sensitivity of the scattering properties to the melting layer model.

The simplified melting model used produces too high LDR values.

More detailed melting models might help, but the scaling of the aggregate mass with size still plays a major role in defining the snow scattering properties.

4. Radar Observation

TRIPex campaign: Vertically pointing ground-based triple-frequency doppler radar

Contributors: Uni. of Cologne, Uni. of Bonn, Karlsruhe Institute of Technology

Location JOYCE supersite - Jülich (Germany) **CASE 24.11.2015**

From 11/11/15 To 1/4/16

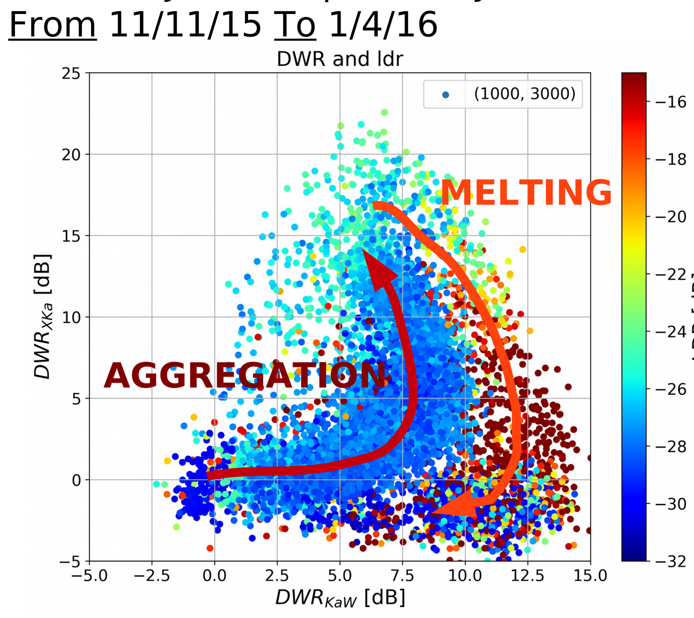

Figure 7: *Observed triple-frequency properties within and above the melting layer. Markers are color coded according to LDR at Ka band. This plot is directly comparable with figure 4.*

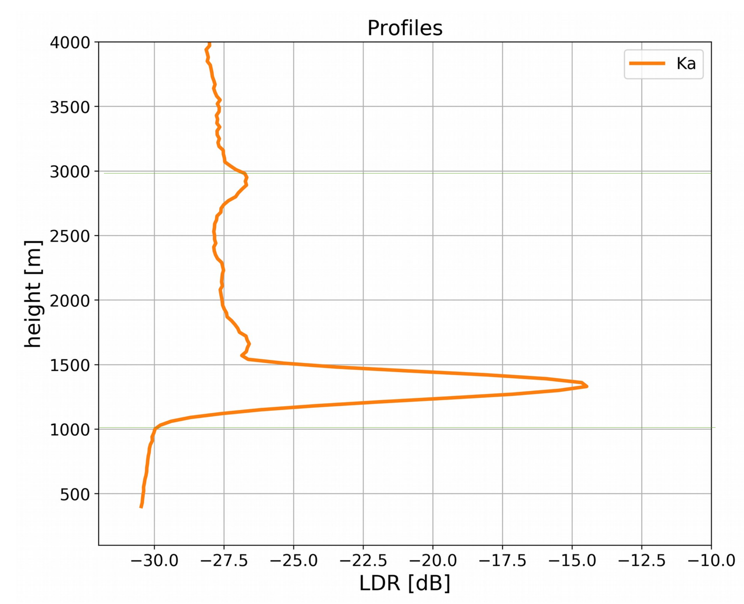

Figure 8: *Observed profile of LDR. The horizontal green lines indicates the range of heights for which figure 7 shows the DWRs*

The observed DWRs (figure 7) are much lower then the modeled, especially the Ka-W which is strongly enhanced by the onset of melting in the scattering modeling.
The LDR profile show increased LDR at the temperature levels know for being favorable for the ice crystals growth which is in accordance with Ori et al. (2014) model.
The absolute value of LDR is not well modeled by the scattering simulations.
The Ori et al. (2014) model matches well the LDR-DWR behavior (figure 9).

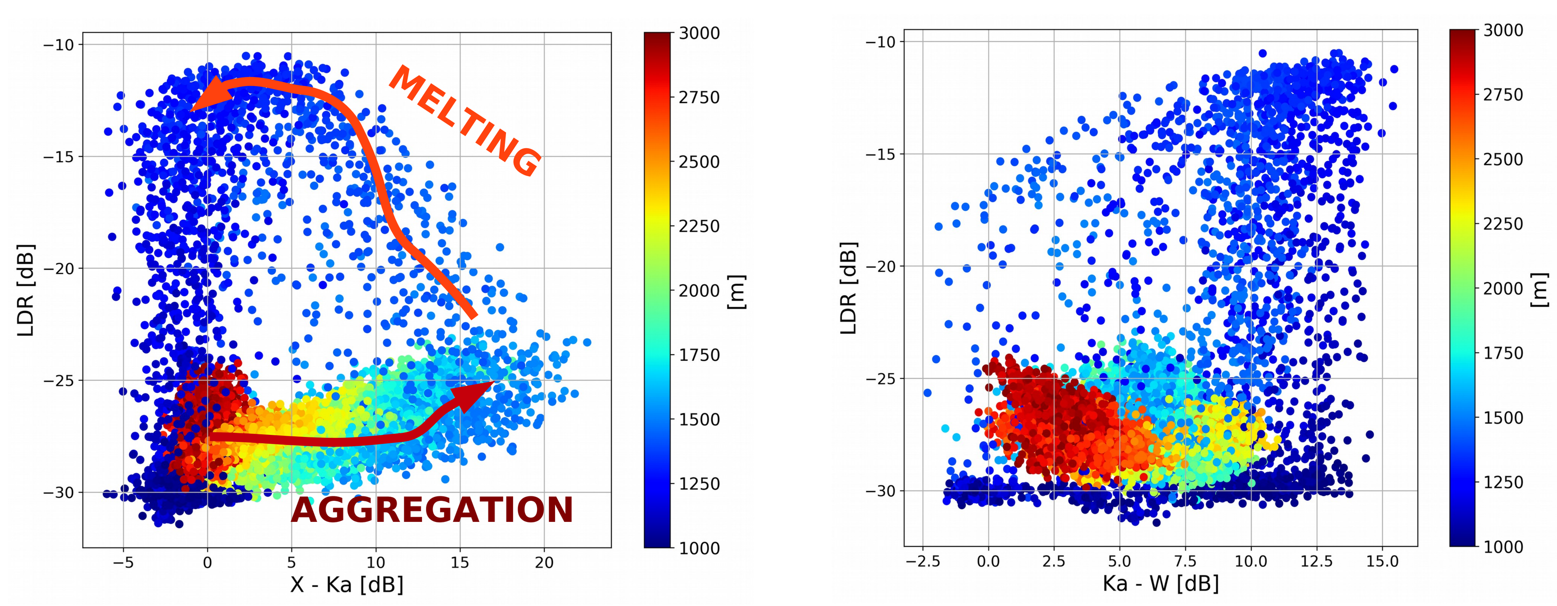

Figure 9: *Observed LDR as function of DWRs. Markers are color coded according to height above the site*

References

Johnson, B. T., Olson, W. S., and Skofronick-Jackson, G.: The microwave properties of simulated melting precipitation particles: sensitivity to initial melting, Atmos. Meas. Tech., 9, 9-21, https://doi.org/10.5194/amt-9-9-2016, 2016.

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Contact: dori@uni-koeln.de