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Atmospheric Measurement Techniques Discussions
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Interactive comment on "Snowfall retrieval at X, Ka and W band: consistency of backscattering and microphysical properties using BAECC ground-based measurements" *by* Marta Tecla Falconi et al.

Marta Tecla Falconi et al.

martatecla.falconi@uniroma1.it

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We thank the reviewer for his suggestions and, in particular, for specific prompts to clarify some fundamental issues. Our detailed replies can be found below in after the "REPLY." label. Changes in the manuscript are highlighted in blue text.

Major comments: Ø General comment: I believe this paper represents a substantial contribution in not only collocating multiple-frequency radar observations with in-situ image measurements of ice particles, but also exploring the capacity of numerical scattering simulations with simplified spheroid models. However, a more detailed analysis of the four cases to show the clear difference between the two precipitation modes is needed. Furthermore, a discussion on the physical reasons of separating into such two precipitation modes would be more valuable.

Ø Specific comments: 1 It is not clear what the definition of fluffy snowfall and rimed snowfall is. Based on the paper, fluffy snowflakes refer to small low-density ice particles, while rimed snowflakes refer to large high-density ice particles. However, low-density ice particles can be large if there is a high number concentration of ice crystals and they aggregate to large particles. Riming occurs when ice particles collect super-cooled cloud drops through a super-cooled liquid layer. So density can probably separate fluffy and rimed snowflakes, but not size. Please provide more information and evidence, e.g., PIP images, about the details on what exactly separate the two precipitation modes.

REPLY. Thank you for pointing out the problem. We agree on the fact that the original definition of rimed and unrimed snowfall was vague and not properly explained. In the modified manuscript we are using microwave observations of liquid water path (LWP) to separate events into lightly, moderately rimed and heavily rimed snow. Even though LWP is not a direct measure of degree of riming, LWP and riming are related as shown for example in (Moisseev et al., 2017).

2 Discuss why the two precipitation modes have such a difference in a and b coefficients in the Ze-S relationship?

REPLY. As shown by von Lerber et al (2017), the prefactor of the instantaneous Ze-S relation depends on particle physical properties (expressed in terms of prefactor of RCS(D) relation) and intercept parameter of PSD. The exponent of Ze-S relation depends on the exponent of RCS(D) and the shape parameter of PSD. In the Rayleigh regime, the dependence of radar cross section on D, RCS(D), is given by (m(D))ˆ2. It should be noted, that for the Ze-S relations derived for an event or averaged over several snowfall storms, the above-stated dependence becomes less clear because of changes in m(D) and PSD.

For higher radar frequencies, RCS(D) relation is no longer given by (m(D))ˆ2. For example, the exponent of RCS(D) will become smaller. Also the prefactor would change. These changes explain changes in Ze-S, as we go from one frequency to another. However, the observed difference is also caused by changes in PSD, and RCS(D), during the events. The variability in PSD and RCS(D) is probably different for different snowfall type. At the moment, we cannot separate the effects and it is not clear what is the main cause for the changes in a and b coefficients. However, it appears that as we use higher radar frequency the difference between Ze-S prefactors for different snow types becomes smaller.

3 Page 13 line 12: "The latter consideration leads to the conclusion that the soft-spheroid approximation may work rather well for computing radar reflectivity since the errors for larger particles are compensated by those for smaller particles". This conclusion is very questionable, because particle size distribution (PSD) does change and it changes the weight between small and large particles. The error might cancel out in specific cases, but not always.

REPLY. We agree with the reviewer's comment. But in the order to study the impact of the assumed scattering model on retrievals, studies similar to the presented one is needed. For example, it could turn out that given almost exponential PSD and m(D)$\sim$Dˆ2, the observed compensating effect is common. The current analysis is limited and we agree that more studies are needed.

4 Can you add the results from DDA simulation in Figs. 3-6 and 9-12? DDA simulation is only discussed at the end in Fig. 13 in terms of backscatter cross section as a function of size. It will be great to see how the detailed ice particles match with observations.

REPLY. The comparison of TMM backscattering cross sections with DDA has been performed for validation purposes. We are aware of the limitations of TMM and then we wanted to check our results. However this comparison is not the central point of the study and we think that adding further curves to the plots would make them very confusing. On the other hand a parallel study is under preparation that further explore the link between the microphysical and scattering properties of snow where this comparison can be better addressed.

Minor comments: 1 Page 7 line 22-23: ‘This is because the microwave backscatter properties do not depend on the small details, but mostly on the overall structure, at least at cm-wavelength’. This is not true. Backscatter cross section does depend on the details of the structure even at large wavelength.

REPLY. Thank you for the comment. Indeed, we have wrongly used the verb “depend”. The aim was to express that at centimetre and millimetre-wave radar frequencies the small details in a particle structure usually do not significantly affect the backscatter properties. The latter depend largely on the overall shape, which, in the case of spheroid, is determined by the spheroid aspect ratio, rs (Matrosov, 2007; Dungey and Bohren, 1993). In the revised paper we have removed the sentence and explained in more details way we have used the TMM (Page 8 line 1-13).

2 Page 7 line 26: typo looses loses. REPLY. Done.

3 Page 7 line 27: typo dendrities dendrites. REPLY. Done.

4 Page 7 line 29-33: This sentence is not clear. Please revise.

REPLY. The soft-spheroid, used in TMM, and complex particles, used in DDA computations, are particle models. Those are not real particles, but our representations of those. As in all models, there are tuning parameters that need to be adjusted to match the observations. We should note, that reproducing the physical appearance of snowflakes is not one of the goals (at least, not the most important goal) of using such models in microwave remote sensing applications. We need a model that links precipitation rate, IWC, Dm, etc. and radar observations. The soft-spheroid model used in this study, is based on observations of m(D). The observed m(D) is our link to precip. rate. The particle aspect ratio and orientation are free parameters. The particle aspect ratio is a particularly important parameter, because it controls density and therefore the refractive index. More discussion on the topic is added to the text (in particular on page 8 line 14-17).

5 Page 8 line 10: Dmax is obtained from PIP. In page 4 line 1, the disk-equivalent diameter DDeq is also obtained from PIP. Are they related? And how?

REPLY: Because of the pre-defined parameter selection with the PIP instrument, the disk-equivalent diameter is recorded. However, in von Lerber et al. 2017, the maximum diameter for each particle is defined by fitting an ellipse to the measured bounding box considering also the orientation of the particle in respect to horizontal direction. The maximum value Dmax of the several observed maximum diameter values is saved. A linear conversion factor between Dmax and DDeq is defined for each snowfall event, and as stated in von Lerber et al. 2017, the value is deviating between 1.20-1.51 and the mean value is 1.38. In the revised paper we added clarification on page 4 line 13-15.

6 Page 9 last paragraph: The particles are randomly oriented from DDA calculations, while the spheroids of TMM are oriented horizontally with 10° standard deviation from Page 8 line 3. Please comments on how the inconsistency affects the scattering results.

REPLY. In this study scattering database for rimed snowflakes by Leinonen and Szyrmer (2015) is used. They have achieved preferential alignment of snowflakes as follows:"To simulate the partial horizontal alignment of snowflakes in the atmosphere, the shortest principal axis of each aggregate is aligned at a normally distributed random angle, with a mean of 0 and a standard deviation of 40". Therefore, both soft-spheroid and complex particles are preferentially aligned horizontally. However, their orientation angle distributions and, probably, aspect ratios do not necessary match. It is possible that the soft-spheroid model needed to fit radar observations does not represent exactly geometrical properties of snowflakes. It is also possible that the complex snowflake model is not physically correct. From the radar remote sensing perspective, if both models are consistent with the radar observations then both particle models are correct. In this study we are introducing one of the methods to judge applicability of different scattering models. Of course, the present dataset is limited and more studies in this direction is needed. We have also added more explanation on Section 3.2 and 3.3.

7 Page 11 line 20: typo. cleare clear.

REPLY. Done.

8 Page 12 line 19: typo. Remove "the" in "For the this case ...". REPLY. Done.

9 Page 12 line 23: typo. Remove "is" or "equals to" in "... is on an average equals to ...". REPLY. Done.

Thank you again for the questions, the supplement to this comment contains the revised AMT manuscript. Changes in the manuscript are highlighted in blue text.

Please also note the supplement to this comment:
https://www.atmos-meas-tech-discuss.net/amt-2017-485/amt-2017-485-AC2-supplement.pdf

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