

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.

General comments: 1 You consider several rimed snowfall cases, but only one fluffy snowfall. I think that based on only one case, it is premature to make a conclusion that the coefficients in the fluffy snowfall Z-S relations have different from rimed snowfall

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frequency tendencies (Page 11, lines 29-31).

REPLY In the revised manuscript we split the cases according to LWP. We agree that more data is still needed to make a more solid statement, but we believe it can be quite representative as a preliminary attempt.

2 Radar calibration issues. Section 2.3. How did you ensure resolution volume collocation from the vertically pointing radars and the scanning C-band radar at cloud top where Rayleigh scattering is assumed for all frequencies? What about the absorption in supercooled liquid which is different at different frequencies?

REPLY The C-band radar was performing RHI scans over the site every 15 min. The observation from these observations are used for cross calibration. We have followed the approach of Hogan et al., 2000 selecting the region to statistical analysed the calibration manually by looking to the radar profiles at C-, X-, Ka- and W-band. We have compared the radar measurements in regions close to cloud top (height higher than 5 km) where we can expect ice hydrometeors to be mostly Rayleigh scatters, and thus, their reflectivity factors should be frequency independent. Furthermore, only the cases where there was no precipitation below were selected.

3 Why did you use the gamma size distribution model (Page 8) rather than directly using PIP observed size distributions expressed in snowflake size bins?

REPLY. Thanks for the suggestion. We have added Figure 13 (a) that shows PSD for the snowfall case of 12 February 2014 and (b) PSD for snowfall case of 15/16 February 2014, to better clarify the variable shape of experimental PSDs derived from PIP measurements. In Figure 13 (a)-(b) red points are representative of the normalized PSD measured by PIP, dashed black line represents the normalized estimated Gamma-PSD in Equation 4 and green line is the last one truncated at the maximum value of 2.5 multiplied by the median diameter D_{0} . Then we have used the Gamma-PSD instead of PIP measured one because the modelled distribution seems more regular in terms of general trend (as is visible in Figure 13). Only to clarify we show three scatter-plot

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in Figure B, one for each band, exploiting the comparison between the Gamma-PSD and the measured one. We can conclude looking at Figure A that the mean errors are decidedly small. In the revised paper we have clarified this point on page 11 line 13-21.

4 It would be helpful if, for each frequency, the authors provide figures showing your best Ze-S relations (given in bold font in Table 3 for individual snowfall events) and some previous relations from literature. You cite a number of such relations for W and Ka-bands. For X-band also there have been a fair amount of previous studies (for example, Boucher and Wieler *Journal of Climate and Applied Meteorology* 1985, p.68; Fujiyoshi et al. *JAM* 1990, p. 147; Matrosov et al. *JTECH* 2009, p.2324; Huang et al., C-band, *JTECH* 2010, p. 637).

REPLY. Thanks for the useful suggestion. In the revised paper we have inserted a “new” Table 4 with the literature based Ze-S relations for X-, Ka- and W-band. We have also clarified the relation between our Ze-S relations and the relations from literature by adding an extended comment at Table 4 on page 12 line 26-33.

5 It would be interesting to know if Ze-S relations derived for the IKA C-band frequency would be much different from those at X-band?

REPLY. We have omitted to use the IKA C-band frequency both because is not collocated in the same BAECC field station but at 64 km west from Hyytiälä in Ikaalinen and also because the IKA radar acquired RHI scans. For the Ze-S relations derived for IKA C-band we remind to Table 3 (replaced below this comment) of von Lerber et al., 2017.

Specific comments: 1 Page 5 line 16: It is stated that ARM radar measurements were corrected for attenuation. Is it attenuation due to accumulated snow on the radome or attenuation in falling snow?

REPLY. We have applied the atmospheric Millimeter-wave Propagation Model (MPM) that predicts attenuation, delay, and noise properties of moist air at frequencies up to 1000 GHz (Liebe, 1985). The attenuation due to the radome or attenuation in falling

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snow has been avoided by making a sky-noise analysis, as written in Section 2.3 (now, 2.4). When there are sudden jumps in the sky-noise temperature, it means that the increase of the surface temperature may be responsible for the snow melting and then for the radome attenuation. We have avoided all data in which these jumps were present. In the revised paper we have clarified this point in Section 2.4.

2 It is not clear if in your modeling you assumed the preferential orientation of the particles (Page 8, lines 1-5) or random orientation (Page 9, lines 27-31). I do not understand your term “randomly orientated particles at fixed orientation”. Please clarify.

REPLY. The scattering database for rimed snowflakes by Leinonen and Szyrmer (2015) is used in our work. Leinonen and Szyrmer (2015) 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.

3 Fig. 8: What coefficients are shown in Fig. 8? Are those corresponding to the dashed black lines in Figs. 3-7? Or something else?

REPLY. In the revised paper we have changed Figure 8 in Figure 7 having changed also the dataset separation in lightly, moderately rimed and heavily rimed snow. Now

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Figure 7 shows the coefficients from Table 2 and 3.

4 Can you provide in Table 2 coefficients corresponding to the dashed black lines in Figs. 3-7?

REPLY. Thanks for comment to improve clarity of the captions. We changed both Table 2 and Figures 3-7 now corresponds to Figures 4-6. Then now coefficients in Table 2 correspond to the dashed black lines in Figures 4-6.

5 How did you obtain D_{\max} from the disk equivalent PIP measurements of D_{deq} ?

REPLY. See reply above to the Minor Comment n. 6 of the Reviewer n. 1.

6 Fig. 9. What is D_0 in this figure? Is it the same as given by eq. (6)?

REPLY. Thank you to highlight the missed and wrong definition. In eq. (6) we missed to define D_0 , V_{eq} as the median volume diameter obtained from D_{\max} , now we have added all the definitions.

7 Page 4 line 23: mm of water?

REPLY. Yes, we have indeed missed to add that the weighing precipitation gauge measured mm of water. We have added it in the revised paper.

8 Radar calibration: As the IKA radar has a vertical resolution of about 1 km at the ARM site (1 deg @ 64 km) did you averaged vertically ARM radar measurements in vertical to match this resolution?

REPLY. Yes, to reduce the beam mismatch and to facilitate comparison to the ground-based sensors, all the radar data are averaged to 5-minutes. In the revised paper we have clarified this point on page 7 line 18-21 and in Section 2.

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.

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Please also note the supplement to this comment:

<https://www.atmos-meas-tech-discuss.net/amt-2017-485/amt-2017-485-AC5-supplement.pdf>

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-485, 2018.

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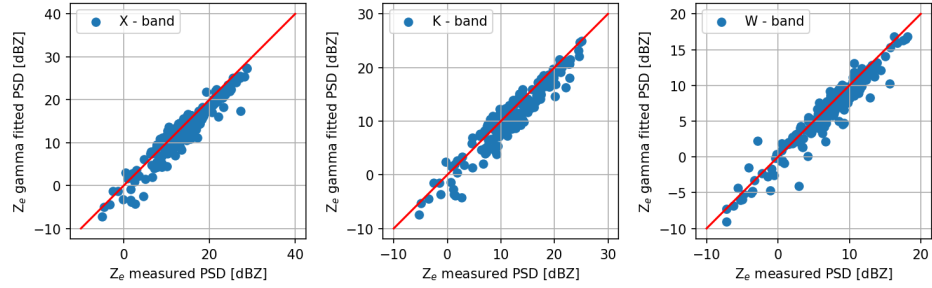


Fig. 1. Figure A

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TABLE 3. The prefactors and exponents of the $Z_e = a_{zs} S^{b_{zs}}$ relation during BAECC SNEX 2014, with Z_e in millimeters to the sixth power per meter cubed and S in millimeters per hour.

Date (UTC)	a_{zs}	b_{zs}
2100 31 Jan–0600 1 Feb	52.5	1.29
1000–1600 1 Feb	143.4	1.41
1600–1900 2 Feb	102.3	1.19
0400–0900 12 Feb	160.0	1.65
2100 15 Feb–0200 16 Feb	114.3	1.32
1600 21 Feb–0330 22 Feb	146.5	1.30
0500–0700 15 Mar	143.2	1.44
0800–1900 18 Mar	290.9	1.41
0000–2000 19 Mar	781.8	1.52
1600–2350 20 Mar	87.3	1.61

Fig. 2. Table von Lerber et al., 2017

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