Interactive comment on "Bulk density and its connection to other microphysical properties of snow as observed in Southern Finland" *by* Jussi Tiira et al.

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The authors appreciate the constructive criticism and helpful comments and suggestions from the Anonymous referee #1. We have addressed each of your concerns in our response below.

A marked-up version of the manuscript indicating the changes we have made is attached as a supplement to this response and all page and line numbers in our comments are in reference to that document.

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Discussion paper

1   General comments

Q1.   *I am concerned about adequacy of the discussion about the relation between snow depth and bulk density of falling snowflakes. The bulk density as given by (8) assumes some snowflake shape (a spheroidal shape in this case). Such snowflakes cannot be stored at the ground compactly (without air volumes between them. These internal air volumes would increase the snow depth on the ground. Snow compression on the ground might counteract this to a certain extent but the total effect is not known. Due to this I do not think the rho(t) in (9) and rho(t) in (10) are exactly the same quantities.*

Response. Thank you for your comment. We have added an extensive discussion on this.

Changes. Added a paragraph starting p.9 l.9 and some supplementary sentences in the previous and following paragraphs. Revised Eq. (10).

Q2.   *The bulk density which is sought in this study represents the whole PSD: rho=rho(Do). In many previous studies, starting probably from Magono and Naka-mura (1965), the bulk density was understood as the density of an individual snowflake defined as the ratio of the individual particle mass, which has a size D, to its volume: rho=rho(D) (for example to the spheroidal volume as this is the shape used in your study too). It causes a confusion. The Brandes et al. (2007) paper, for example, compares bulk densities from two different definitions in their table 2 and Fig. 6a. However, rho(D) is not the same as rho(Do), they are different parameters. I suggest that you clearly state different definitions of bulk densities used previously to minimize confusion for potential readers.*

Response. It is a very good point. We have added discussion about the different definitions, and the density related terminology has been partly changed and more

accurately described. To avoid confusion with the term "bulk density" and its multiple definitions, we chose to use the term "ensemble mean density" instead. As of notation, $\bar{\rho}$ is now used to denote ensemble mean density instead of ρ.

Changes. Added discussion starting p.2 l.26.

Q3. What are uncertainties of estimating bulk density and the coefficients in m-D relation? Some discussion is needed here.

Response. We have added more discussion and performed a simulation study to quantify some of the uncertainties.

Changes. Uncertainties due to PSD truncation are discussed in the new Chapter 3.4 (p.9, l.35) and from p.14 l.17 onwards.

Q4. You estimated coefficients a_m and b_m in the m-D relation assuming the exponential distribution and just one value of bv=0.217. According to the data in Figs. 5-6, bv changes relatively widely from 0.208 to 0.256. How this variability in bv would change the derived coefficients in the m-D relations? Also what is influence of variations in the mu factor?

Response. We have computed the m-D relations to the different exponent values b_v of v - D relations defined in Equations 11-13 for different bulk density ranges and the results are stated in Table 2. It can be seen that the prefactor values a_m are not sensitive to changes of b_v (this is stated on p.14 l.27 of the revised manuscript), a_m values change less than 1% as the values of b_v deviate. In respect to influence of μ, by deviating μ from values of 0 to 3, the a_m is changing nearly 48%, increasing as μ is increasing. The influence of μ is now described starting p.14, l.28.

2 Specific comments

Q1. Section 3.1: It appears that you model particles as oblate spheroids. Please provide some discussion to justify this model.

Response. We have added a new figure, the new Fig. 2, and more discussion, especially in the Section 3.1.

Changes. Discussion starting p.6, l.8.

Q2. Equations (4)-(7) are obtained assuming integration from 0 to infinity. In reality there is not only truncation due to particle maximum size, but also due to the smallest considered size being 0.2 mm (not zero) as shown in the last line of page 5. Can you estimate errors due to realistic integration limits?

Response. We have performed a simulation study to quantify this effect. The results of this study are summarized in Fig. 6. As you can see, we are overestimating density. For D_0 larger 1 mm, most of our observations, this overestimation is below 5%.

Changes. New Chapter 3.4 (starting p.9)

Q3. Equations (8) and (9): again why the lower integration limit is 0 (not 0.2 mm)?

Response. It is now changed to D_{min}.

Q4. Equations (17)-(18): put the integration limits. What would be the effect of using the non-truncated integral as given by (19) instead of smaller values which the truncation and non-zero lower limit provide.

Response. it is discussed in more detail now, see answer to Q2.

Q5. How changing the assumption of the aspect ratio (currently 0.6) would change your lines in Fig. 9?

Response. The change in the aspect ratio would have a noticeable effect on the lines in Fig. 9 (new Fig. 10), at least if the m-D relation would be retrieved from a single event. The impact of the aspect ratio assumption on the retrieved density is now discussed in the Section 3.1. (starting p.6, l.15) However, since we are using measurements from several events, and comparison to snow depth measurements indicates that there are no large systematic biases, we are believe that presented average m-D relations are valid.

3 Technical comments

Q1. I suggest indicating in the title and introduction that you are deriving the density of FALLING snow. I tend to believe that the density of falling snow and the density of snow on the ground are different (see the general comment 1.

Response. Changed "snow" to "falling snow" in the title.

Q2. Page 3, Line 11: Indicate here which "couple of days" from Table 1 were used in this study.

Response. The events that "extended over a couple of days" referred to events that extended past midnight (UTC). The superfluous clause "where a number of events extended over a couple of days" was removed to avoid confusion.

Q3. Page 11, line 6: the subscript "m" should be at the "b" level not at "D".

Response. Corrected.

Q4. *The citation to Matrosov 2007 from Table 3 and Fig. 9 is not in the reference list.*

Response. Corrected.

Q5. *Page 9, line 22: Is it "all the cases" from Table 1?*

Response. Yes. It is now written "all the cases in Table 1".

Q6. *Add units for density in Figures 7, 10 and 12.*

Response. The units are given in the captions to save space in the figures.