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Interactive comment on "A bulk parameterization of melting snowflakes with explicit liquid water fraction for the COSMO model version 4.14" *by* C. Frick et al.

Anonymous Referee #2

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Review of "A bulk parameterization of melting snowflakes with explicit liquid water fraction for the COSMO model version 4.14" by C. Frick, A. Seifert and H. Wernli.

The paper describes a parameterization of melting snowflakes explicitly considering the liquid water fraction of the melting particles as a prognostic variable, building on earlier work by Mitra et al. (1990) and Szyrmer and Zawadzki (1999). The parameterization is described in detail and is followed by two case studies that show the impact of the model changes. The work addresses a difficult problem for NWP in determining precipitation type where near-surface temperature is slightly above zero. The paper is well written, describes a novel bulk parameterization implementation in an NWP model and is appropriate for publication in GMD. However, there are a couple of major com-

ments that may affect many of the results in the paper which should be addressed before publication. There are also a number of minor corrections.

MAJOR COMMENTS

1. Calculation of capacitance

The authors have chosen to express the analysis in terms of the maximum geometrical dimension of the mass equivalent dry snowflake, D_s, assuming a density relation of m=0.069*D_sˆ2. Equally the authors could have chosen the diameter of the mass equivalent melted sphere, D_eq. The rationale would be the same, i.e. the diameter is constant following a particular particle throughout the melting process (as is the total mass of the particle). In contrast, the actual melted diameter would change (decrease) through the melting process due to increasing density, from the dry snowflake diameter, D_s, to the melted sphere diameter, D_eq.

The use of a constant diameter assumption (in this case D_s) has a number of consequences. Firstly, there is a discontinuity at the point where all snow has turned to rain, which the authors point out for the assumption of size distribution on p2939. Secondly, particle characteristics that depend on diameter, such as capacitance can be incorrectly calculated for melting particles if not carefully accounted for.

The capacitance is a term in the melting rate, and for a melting particle, is defined as a function of D_s and an increasing function of meltwater fraction, l, (Eqn 9) so for a melting particle with constant D_s, the capacitance increases with increasing meltwater fraction. Assuming constant density throughout the melting process D_eq is proportional to D_sˆ2/3, so the capacitance also increases with constant D_eq, which is plotted in Figure 1a. In fact, the capacitance should *decrease* as the particle melts due to an increase in the density and decrease in melted diameter. Eqn 9 should include a modification term for the particle density, which was taken into account in Mitra et al. (1990), but isn't here. M90 assumed a linear increase in density from 0.02 for a dry snowflake to 1 for a raindrop (linear with melted water fraction). This will then lead to a smooth transition to the capacitance of a raindrop.

The result of this change will be a lower melting rate as the melting proceeds, which will change the results in all subsequent simulations and figures.

2. Calculation of ventilation coefficient

For the ventilation coefficient, it is not clear how the Reynolds number is specified as a function of l. Do you use Eq 13 with interpolated terminal velocities between a dry snowflake and a rain drop calculated from Eq 11? A bit more detail would be appropriate. It is not so clear why there is so little dependence of the ventilation coefficient on equivalent diameter from rain to snow given the large change in terminal fall velocity - is this because the smaller melted drop size compensates exactly for the increased terminall fall speed? Figure 1(c) is very different to the equivalent plot in SZ99 (fig 2) which has the ventilation coefficient increasing significantly for increasing meltwater fraction. If there is a good reason for the differences, this should be explained.

[Note the empirical terminal fall velocity formulation in Fig 1(b) does look reasonable, and is consistent with SZ99 Fig 1. Might be a good idea to separate this section with subtitles, i.e. a) Capacitance, b) Terminal fall speed c) Ventilation coefficient?]

MINOR COMMENTS AND GRAMMATICAL SUGGESTIONS

- Although I realise the model version "version 4.14" in the title has been requested by the journal, I don't think it is necessary or appropriate in this case? The paper is not a description of this particular model, but rather a description of a parametrization that is more generally applicable.

- Abstract, p2928, line 12-13 I would suggest a slight reordering of the sentence to "For the bulk parameterization, a critical diameter is introduced which increases during the melting process. It is assumed that particles smaller than this diameter have completely melted..."

p2929

- line 18, Correct "Szyrmer and (1999)"

- line 22, Why "potential melting" and not just "melting"?

- line 28, "is called the melting layer"

p2931

- line 11, "...and the subject of future investigation."

p2932

The text describes exponential or Gamma, but Eq. 3 describes only an exponential. Given the discussion here, it would be more appropriate to put the equation for a Gamma distribution (i.e. include f(Ds) = N0 Dˆmu exp(-lambda Ds) and then reword the text to include mu=0 for exponential in the text. Also be consistent using either "inverse exponential" or "exponential". The differences are really for the small end of the particle size spectrum and so it depends to some extent on the application. For mass changes, the mass-weighted part of the spectrum dominates and therefore an exponential is a reasonable assumption.

For Eq. 4, for completeness should really include definition of rho symbol, i.e. density of air.

p2933

- Equation 5, maybe you could put dLs/dt = -dmw/dt = ... to link with Eq. 2, i.e. snow loss is meltwater gain.

- line 24, Szyrmer reference missing something.

p2934

- line 22, the "size of the mass equivalent dry snowflake D_s depends itself on the mass equivalent diameter of the melting snowflake, D_eq and l" (the meltwater fraction). However, it appears from the text that D_s is only a function of D_eq, as both D_s and

D_eq are assumed to be constant as the particle melts, i.e. constant density.

p2935

- line 18 "terminal fall velocities of the mass equivalent dry snowflake", but vs and vr in Eqn 11 are expressed as functions of Ds and Dr, which are the maximum dimension (even though these are functions of Deq). Some inconsistency in notation/description here.

p2936

- line 2, is the D in cross-sectional area, D_s or D_eq?

- line 13, Split the sentence, i.e. "...Reynolds number deviates from M90. Instead we are consistent..."

- Eq 13. define v_a, i.e. kinematic viscosity

p2937, Eq 15. should be L_si = rho q_si

p2939, line 4, remove comma after "both,"

p2940, Eqns 21,22, Would help to point out here you are using m_i=alpha*Dˆ2

p2942, line 11, "That makes it possible..."

p2943

- line 3, commas..."To approximate, e.g. the melting integral, we chose..."

- line 20, "According to the limitations..."

p2945

- line 2, remove "to do"

- line 16, as q_s,w uses a "new generalized tracer implementation", does this use the same advection scheme as q_s,i? If not, then what impact does this have?

p2946, line 20, "at 850hPa"

Figure 3, Units for (a) and (b)?

Figure 4, Could a box be added to the plot to show the area in Figure 5 for those not so familiar with the geography of Germany.

Figure 5, Contour labels are incorrect colours, meltwater is red, 0degree is green and cross section is black. Lines on the figure could be clearer, but maybe in the final version it will be a bit bigger?

p2948, line 4, "bulk liquid water fraction". Be clearer that this is the fraction of the snow that is meltwater so that the following discussion is clear. Maybe "meltwater fraction" is a better phrase?

p2950

- line 5, "this might be due to the fact...". Can you not be more certain about this through diagnosis of what the scheme is doing?

- line 14/15, "explicitly predicting" -> "explicit prediction of"

- line 19, "to receive"? Do you mean "to determine"?

p2951

- Line 1 "The liquid water fraction..." Again be clearer that this is the meltwater/snow fraction. Maybe "meltwater fraction" is a better phrase?

- line 21,22 The last sentence reads a little oddly to finish on: "could be ideal", "some assumptions". I would suggest something like: "A comparison with radar data would allow an assessment of the vertical structure of the simulated melting layer, which is sensitive to the assumptions made in the snow melting scheme"

or:

"A comparison with radar data would allow the accuracy of the vertical structure of the simulated melting layer and assumptions in the snow melting scheme to be assessed."

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