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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.

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Reply to Referee #1

Reviewer Comments are marked by **RC** and Author Reply by **AR**.

We thank anonymous referee #1 for pointing out that, in addition to the presented snow fraction, the ice fraction is an interesting and more direct measure for the

C1325

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Interactive Discussion

Discussion Paper



melting rate of the COSMO model. Additionally, we really appreciate the identification of the wrong maximum dimension used for the calculation of the capacitance. We fixed this mistake, included the new calculation to the parametrization and resimulated our case studies.

GMDD

6, C1325–C1332, 2013

Major Comments

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1.
 - **RC** Fig 1a. shows the size dependence of the capacitance of dry and wet snow flakes. In my opinion the calculation of capacitance may be incorrect. Contrary to the plots in the figure the capacitance of the water drops should be the smallest ($0.5 \cdot D_{eq}$), if the masses (or D_{eq}) are the same. The physical base of this statement is: if masses are equal, the surface of a sphere is smaller than that of an oblate spheroid or that of a hexagonal plate. In my opinion the source of this problem is that the mass – size relation of $m \sim D^2$ is used for the melted particles as well. The problem can be solved if both the exponent and the multiplication factor (α) are given as a function of the liquid water fraction.
 - **AR** Actually, the referee is correct. For the same mass, the capacitance of the raindrop should be smaller than the one of the snowflake. In Eq. (9) of the discussion paper we incorrectly applied the diameter of the dry snowflake D_s instead of using the diameter of the melting snowflake D_m as suggested by Mitra et al. (1990). We corrected this mistake:
"For the calculation of the capacitance M90 applied the approximation for an oblate spheroid. The axis ratio is assumed to be 0.3 for a dry dendritic crystal, and 1.0 for a raindrop. The axis ratio for melting snowflakes is approximated by a linear interpolation, i.e.,

$$a(l) = 0.3 + 0.7 l. \quad (8)$$

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and the capacitance is then given by (Pruppacher and Klett, 1997, p. 547, Eq. (13-78)),

$$C_m(D_s, l) = \alpha_{\text{cap}}(l) \frac{D_m(D_s, l)}{2} \frac{\sqrt{1-a(l)^2}}{\arcsin \sqrt{1-a(l)^2}} \quad (9)$$

with $C_m(D_s, 0) = C_s$ and $C_m(D_s, 1) = C_r$. D_m is the maximum dimension of the melting snowflake, which can be calculated as follows

$$D_m(D_s, l) = \left(\frac{6m_s}{\pi a(l) \rho_m(D_s, l)} \right)^{1/3} \quad (10)$$

assuming an oblate spheroid shape of the melting snowflake (see above) and in agreement with Eq. (8) of M90. Here ρ_m is the density of the melting snowflake. As suggested by M90 we interpolate $\rho_m(D_s, l)$ between the density of liquid water, $\rho_w = 1000 \text{ kg m}^{-3}$, and the density of the dry snowflake $\rho_s(D_s, l)$:

$$\rho_m(D_s, l) = \rho_s(D_s, l) + (\rho_w - \rho_s(D_s, l))l. \quad (11)$$

For the density of a dry snowflake with the axis ratio of the melting snowflake it follows from the assumption of the oblate spheroid shape that

$$\rho_s(D_s, l) = \frac{6m_s}{\pi D_s^3 a(l)} \quad (12)$$

but only till a maximum value of $\rho_s = 500 \text{ kg m}^{-3}$ because higher densities are not reasonable for snowflakes. The empirical correction factor $\alpha_{\text{cap}}(l)$ in Eq. (9) is about 0.8 for dry snowflakes and for melting snowflakes M90 again suggest a linear interpolation, i.e.,

$$\alpha_{\text{cap}}(l) = 0.8 + 0.2 l. \quad (13)''$$

The resulting capacitance is presented in Figure 1 below. As mentioned by the referee, the capacitance of a rain drop is now smaller than the one of a snowflake with the same equivalent diameter D_{eq} and for a completely melted snowflake the capacitance becomes $D_{eq}/2$.



Interactive
Comment

This detailed description of the new calculation of the capacitance (equation numbers correspond to the new version of the manuscript) has been included to the paper and the corrected formula introduced to the parametrization which leads to a modified melting integral (Figure 3 of the discussion paper). Consequently, all case studies have been resimulated. The results only show minor differences compared to the previous simulations and our major findings stay unaffected.

2.
 - **RC** If I understand well the snow means the sum of melted water and ice core in Fig 9b. I think it would be also interesting to plot a similar figure by taking into consideration the ice core only. Comparison this figure with Fig 9a would show how the application of new scheme affects the melting rate.
 - **AR** We calculated the ice fraction $q_{s,i} / (q_s + q_r)$ for the new melting scheme. For the standard scheme, see Figure 2 below, ice fraction and snow fraction are equal. For the new scheme, see Figure 3 below, the resulting density distribution of the ice fraction is more compact than the one of the snow fraction shown in the Paper in Figure 9b. Additionally, the slope is slightly steeper for the first 10 to 20 hPa below the freezing level. Compared to the standard scheme, we find a deceleration of the melting process and a significant reduction of the melting rate, especially for distances to the top of the melting layer larger than 20 hPa. We added a short comment on the ice fraction to subsection 3.3:

"In general, the melting rate is reduced by the new melting scheme. This finding is also supported by the evolution of the ice fraction ($q_{s,i} / (q_s + q_r)$, not shown) which has a slightly more compact density distribution but a slope comparable to the one of the snow fraction."

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1.
 - **RC** The colors of contours in Fig 5. do not agree with text in the figure caption.
 - **AR** Corrected.

6, C1325–C1332, 2013

Interactive
Comment

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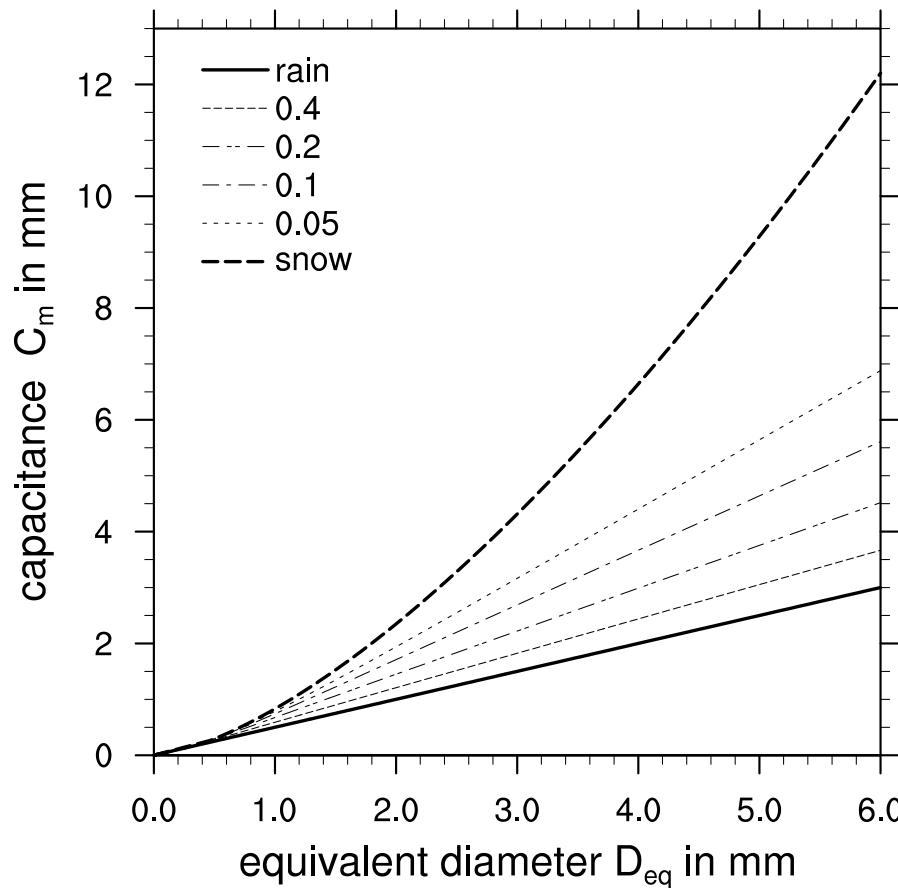


Fig. 1. The capacitance of a snowflake during the melting process for different liquid water fractions using the corrected formulation as presented in Eq. (9).

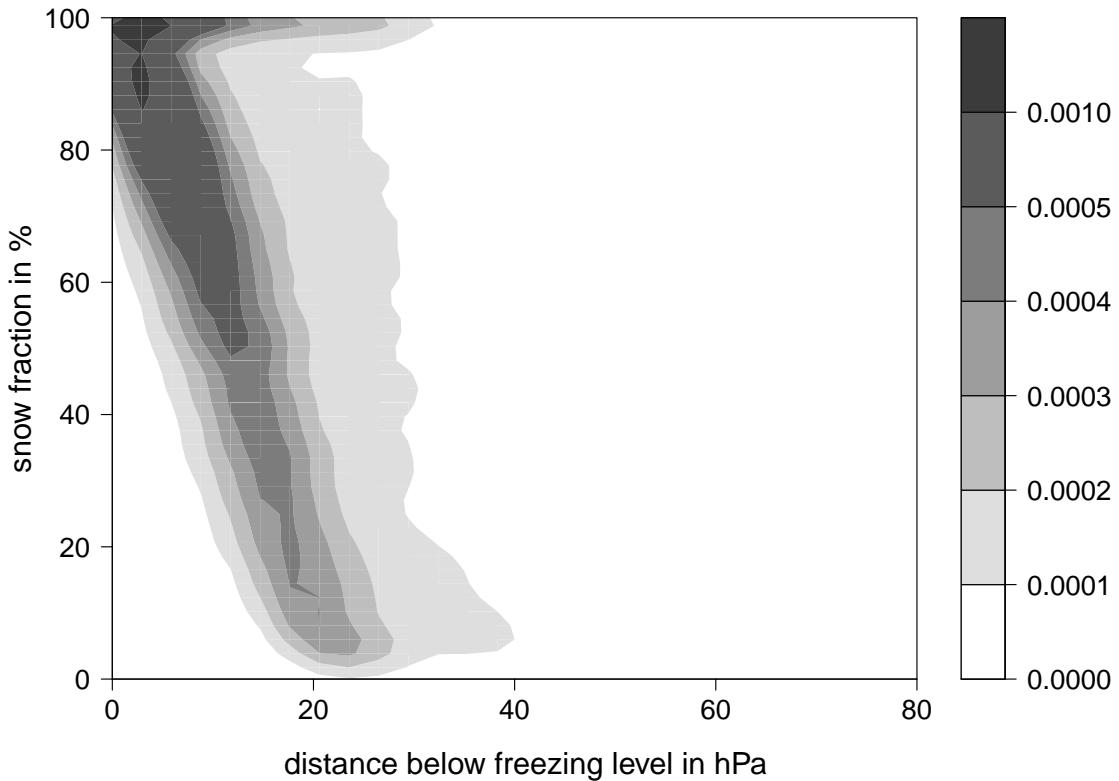
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Fig. 2. The ice fraction of the standard scheme depending on the distance to the top of the melting layer.

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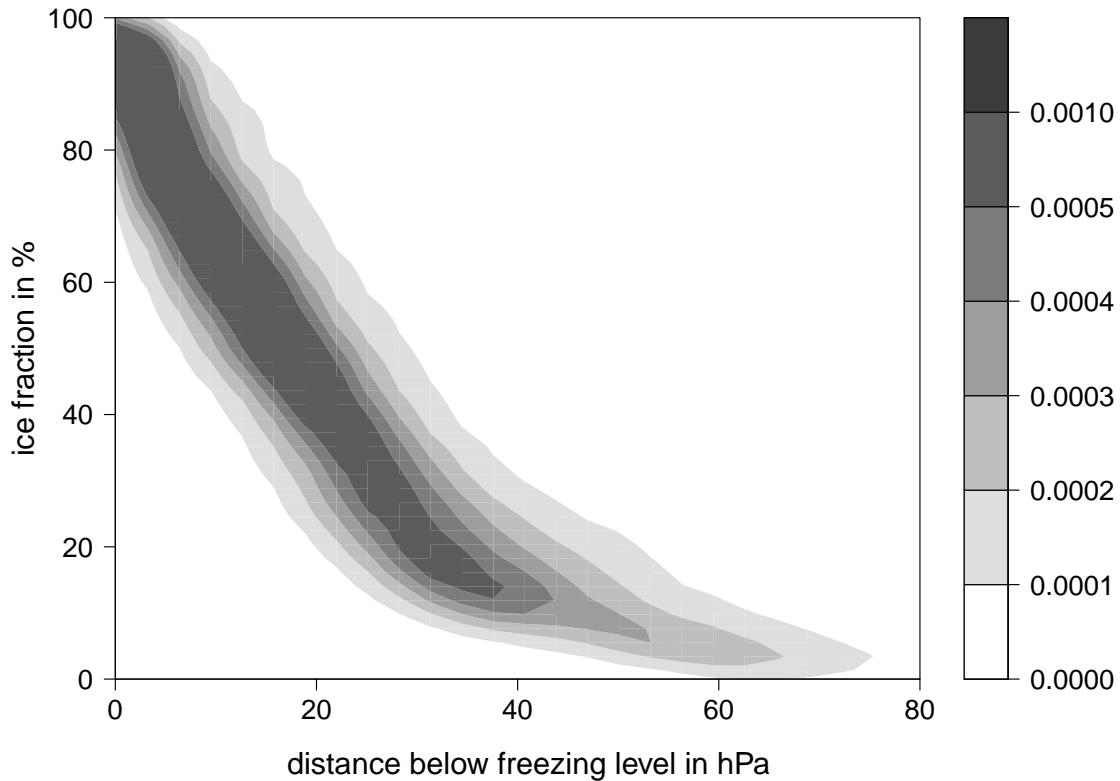
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Fig. 3. The ice fraction of the new melting scheme depending on the distance to the top of the melting layer calculated by using the parametrization with the updated capacitance calculation.

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