Note: Reviewer's original comments are in black text and author responses are in blue text

Anonymous (Referee #2)

This study incorporates four different representations of snow specific area (SSA) into the Crocus model, and evaluates simulated snow states against observations from Greenland and the French Alps. One of the SSA representations is new, and essentially updates earlier representations of snow grain characteristics from Brun to provide the more relevant quantity of SSA. Overall I think this is a very useful study that includes both new measurements of SSA and evaluation of multiple SSA parameterizations.

We really thank the Referee for this positive evaluation and for taking the time to review and provide feedback on this paper. We have modified the text in response to her/his comments as detailed below.

Several minor issues should be addressed before publication. The paper needs a clear and concise description of how the SSA representations differ between B92 and C13. Some information on this is contained in sections 2.1 and 2.3, but the differences are still unclear to me. The issue I am most confused about is how SSA is determined from B92, given that SSA was not a prognostic quantity from the original representation, as indicated in Table 1.

We thank the Reviewer for this comment. The only significant difference between the formulations B92 and C13 appears when strong temperature gradient conditions occur. In this case, C13 leads to lower SSA values compared to B92. This was discussed in Sect. 2.3.1 of the original manuscript:

"When G > 15 K·m^{-1} and s = 0, d_{opt} of non-dendritic snow increases over time following the parameterization of Marbouty (1980), which allows to predict depth hoar growth rate. In the original B92 formulation, non-dendritic d_{opt} became a function of g_s only when the latter exceeded an empirical threshold set to 8·10^{-4} m. In C13 we do not have any information about g_s and therefore we have removed this threshold. This means that in the case of a strong temperature gradient metamorphism, C13 will lead to d_{opt} values higher than those of B92."

In order to make clearer the fact that these two formulations are equivalent (since they are based on the same rate equations, just formulated in terms of different state variables), we have added this sentence to the end of Sect. 2.3.1:

"Aside from that difference, formulations C13 and B92 are supposed to give the same results, as C13 consists in a reformulation, in terms of optical diameter, of the original metamorphism laws of B92 expressed in terms of dendricity and snow grain size."

Regarding the determination of SSA from B92, the Reviewer raises a question that we feel is adequately answered in Sect. 2.2.2 of the original manuscript (see also Fig 1). In the original version of Crocus, d_{opt} was semi-empirically estimated from the variables dendricity, sphericity and snow grain size using two equations that stem from laboratory measurements. These equations are not reported in our manuscript, as they have already been discussed in previous works (see in particular Eq. 13 in Vionnet et al., 2012 and Eq. 2 in Morin et al., 2013). These equations provide a means to determine d_{opt} (and then SSA) from the microstructural variables used in Crocus. The SSA calculated in this way has also been used in the past to couple Crocus to models of the electromagnetic properties of the snowpack (Brucker et al., 2011).

Minor comments:

(1) Use of "d" to describe dendricity and "d_opt" to describe a diameter is a bit confusing. The authors might consider an alternative symbol for one of these quantities. All acronyms should be defined (e.g., TEB on p.4448,10).

We completely agree with the Reviewer's comment. In the revised manuscript, we have used "δ" (instead of "d") to describe dendricity. In addition, all acronyms have been defined.

(2) p.4449,21: "Snow layer settling upon the combined effect..." is unclear.

We have replaced the word "upon" with "due to" in the revised manuscript.

(3) section 2.3.1: To me, it would make logical sense to begin this section by describing the new prognostic representation of d_opt, listed in Table 2. This is the quantity of focus in the paper, and also the heading of section 2.3.

We agree with the Reviewer that it would be possible to begin Sect. 2.3.1 by presenting the re-formulation of the dry metamorphism laws, instead of putting that part at the end of the section. However, we think that before describing how we have obtained the rate equations reported in Table 2, it is necessary to explain how the new prognostic variable (the optical diameter) has been introduced into the model. For this reason, Sect. 2.3.1 is divided into three paragraphs. In the first one, we describe how we have introduced the optical diameter within the Crocus model. In the second one, we present some of the advantages and the issues encountered during the reformulation in terms of optical diameter of the original model. In the third one, we finally focus on metamorphism and we explain how we have obtained new rate equations for the optical diameter (reported in Table 2). In other words, we understand the Reviewer's point of view, but we think that the current form of this section makes logical sense too.

(4) p.4453,6: I suggest that the authors briefly describe, either here or elsewhere in the paper, how albedo is related to d_opt in Crocus. This is relevant because model albedo is evaluated against observations (e.g., Fig. 10). How sensitive is the model snow albedo to d_opt?

Good suggestion, thank you. A brief description of how albedo is computed in Crocus has been added to Sect. 2.2.2, as reported below:

"The albedo is then calculated from the snow properties of the two upper numerical layers by splitting the solar radiation in three separate spectral bands ([0.3-0.8], [0.8-1.5] and [1.5-2.8] µm). In the UV and visible range ([0.3-0.8] µm), albedo depends on the optical diameter and on the amount of light absorbing impurities, the latter being parameterized from the age of snow. In the infrared bands ([0.8-1.5] and [1.5-2.8] µm), albedo depends only on the optical diameter of snow (Vionnet et al., 2012). For instance, increasing the optical diameter from $1.09 \cdot 10^{-4}$ m (corresponding to a SSA of 60 $m^2\ kg^{-1}$) to $3.27 \cdot 10^{-4}$ m (corresponding to a SSA of 20 $m^2\ kg^{-1}$) leads to an albedo decrease from 0.79 to 0.67 in the range 0.8-1.5 µm."

(5) p.4454,11: Number is missing a "times" symbol.

The "times" symbol has been added in the revised manuscript.

(6) p.4458,12: The meaning of this passage is unclear to me: "this distinction remains true only for the time evolution of sphericity, which is left unchanged."

Formulations T07 and F06 use two variables to describe the snow microstructure. These variables are optical diameter and sphericity. The rate equations of the optical diameter are based on Taillandier et al., 2007 for the formulation T07 and Flanner and Zender, 2006 for the formulation F06. The rate equations of the sphericity are identical to those from Brun et al., 1992 for both formulations. Consequently, since the metamorphism laws of Brun et al., 1992 distinguish between two different regimes (dendritic and non-dendritic), the sphericity is impacted by a change of regime, occurring when snow enters the non-dendritic state. For more clarity, in the revised manuscript we have rephrased the passage as follows:

"this distinction remains true only for the time evolution of sphericity, which is identical to that of B92 for all formulations."

(7) p.4458,16: Number is missing a "times" symbol.

The "times" symbol has been added in the revised manuscript.

(8) p.4467,8: Do "these results" pertain to the RMSD values?

Yes, our results in terms of RMSD between observed and modelled snow heights, SWE and albedo are consistent with previous studies. For more clarity, in the revised manuscript we have rephrased the passage as follows:

"These results in terms of RMSD are reasonable for this site and consistent with previous studies."

(9) Section 4.2.2: The authors refer in several places to times and locations that experience snow melt. It should be noted again in the intercomparison of model SSA that all representations include the same formulation for wet metamorphism from Brun et al (1992), suggesting that we should expect less model diversity in the simulation of wet snow states.

We appreciate the Reviewer's comment. In fact, in case of wet snow the differences between the formulations are only due to differences in the initial SSA values at the onset of snow melt. In order to point out again the fact that all representations include the same formulation for wet metamorphism, in the revised manuscript we have added the following sentence to Sect. 4.2.2:

"Regardless of the formulations considered, the smaller differences are found during the melt period, not only because in this case the SSA values are generally lower, but also because all representations include the same formulation for wet metamorphism (see Table 1)."

(10) p.4471,16-18: "F06 makes the SSA decrease faster in the case of low density": This is only true with non-zero temperature gradients. Hence, the finding that the rate of SSA change under isothermal conditions is independent of snow density (Schleef and Loewe, 2013) is actually consistent with the F06 model. The passage should be reworded to reflect this.

We thank the Reviewer for this relevant input. In the revised manuscript, the paragraph has been modified as follows:

"The only significant difference stands out for the low density layers at the very near surface. Indeed, F06 makes the SSA decrease faster in case of low density layers with non-zero temperature gradients (Fig. 3d in Flanner and Zender, 2006). This dependence on snow density does not appear in the other formulations. Under isothermal conditions, the rate of SSA change is independent of snow density in all formulations. This is consistent with the recent study of Schleef and Loewe (2013), who found that the rate of decrease of the SSA under isothermal conditions, computed on micro-tomographic images, was independent of the density."

(11) Grammar: The following phrases are grammatically incorrect: "allows to write" (4446,20), "allows to simplify" (4447,17), "allowing to test" (4448,3), "allowed to formulate" (4450,7), "allows to compute" (4453,5), "allows to predict" (4454,9).

We thank the Reviewer for pointing out these mistakes. The text has been corrected.