

The Cryosphere Discuss., referee comment RC1  
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## Comment on tc-2021-73

Anonymous Referee #1

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Referee comment on "Elements of future snowpack modeling – part 2: A modular and extendable Eulerian–Lagrangian numerical scheme for coupled transport, phase changes and settling processes" by Anna Simson et al., The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-73-RC1>, 2021

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This paper describes a modular Eulerian-Lagrangian approach solving the coupled non-linear processes. The authors report the shortcomings of the majority of snow models that do not give an explicit numerical solution of the ice mass continuity equation but are built around. The model formulation of the snow scheme presented explicitly accounts for the ice mass balance and couples mechanical settling, heat transport and vapour transport whereby these processes can also be analysed individually due to the modular structure of the model. This modular design of the new approach allows for high degree of flexibility, which the authors use to analyse different isolated and coupled scenarios involving of heat transport, vapour transport and mechanical settling of a dry two-layer snowpack. The work provides a good basis for future work and discussions on the future generation of snow models. The work is very exciting and gives new approaches that will be useful for the snow modelling community. However, I have some suggestions for changes in restructuring of the work and some visualisations.

### Major Comments:

The discussion section lacks comparisons to other studies and observations from which one can see the progress. This would provide an important context for the presented results and an evaluation of the presented results of the different cases and model behaviour. More discussion and comparison would for example be desirable in section 4.2: are there other studies that show the same? Also section 4.3: How about a comparison to observations and other work e.g. for lines 408 to 410?

The authors also use references sparingly in the method sections. For example, section 2.3 get along without using a single reference. If this is a result of the author's work, I recommend emphasising this to the reader.

I recommend restructuring section 4 and using a separate method section for the difference steps you took to apply the model. I suggest moving line 363 – line 379 to a subsection of the methods. I also recommend moving section 4.1 to the methods. For me, the results section starts with line 392.

Section 4.6 and Fig. 10: Here you write that you compare cases 5 and 8 and use Fig. 10 for visualisation. However, Fig. 10 only visualise for case 8. I can only find the visualisation for case 5 in Fig. 6 and 7 but only for different variables or different visualisation. This makes it difficult for the reader to compare the two cases. I suggest adding the visualisation for case 5 in Fig. 10. Also, I cannot find a comparison to case 5 in the text. You describe Fig. 10, briefly compare your results to section 4.2, which deals with case 1, and mention the sublimation peak as observed for other cases. However, I cannot find a comparison to case 8.

### **Detailed Comments:**

Line 20: I suggest to add "e.g. Snowpack, Crocus" behind "when not even detailed snowpack models".

Line 29: Please name the snowpack models.

Line 46: The vapour transport is very important and interesting. I encourage the authors to explore further the importance and the differences in e.g. alpine and arctic snow of the importance.

Line 50-52: See comment above: Please describe in more detail why it is important.

Line 57: Please also add the details for Crocus.

Line 61: You mention that a finer spatial resolution is needed. Please mention the spatial resolution of Snowpack and Crocus.

Line 74: Reference is needed for the current treatment of densification in snowpack models.

Line 80: Define " $\sigma$ -coordinates".

Line 111: Please add a reference where this common starting point is used in snow models.

Line 113: I recommend deleting "without explicitly mentioning every time". You already write "if not stated otherwise".

Line 115: "snow density" did you mean "ice density" ? Please clarify.

Line 114-117: Reference is needed here.

Line 119: Would there be a lot change if wet snow were used? Please clarify in 2-3 sentences the differences that dry snow and wet snow would make (more detailed description of what you have already started in line 121)

Line 121: I recommend adding "compared to wet snow situation" after "as the more challenging (yet less investigated) one"

Line 122: I suggest starting a new paragraph for "Note, that water transport ..."

Table 1: Is there a value missing for density? I suggest ordering the variables within the headings according to their occurrence in the equations. So ice volume fraction first, followed by vertical velocity, etc.

Line 129: "source term c" do you mean ice deposition rate?

Line 132 – 134: You write that vertical motion results either from mechanical settling changes in ice volume from sublimation/deposition. What about melting and snow redistribution?

Line 139: see comment for line 129

Line 141: "Hence we will refer to  $c$  as the deposition rate" I suggest to introduce this term earlier maybe line 129 (see comments line 129, line 139)

Line 152: Please add references for snowpacks where the approach typically chosen in the snowpack models is apparent.

Line 170: Which properties of the snow microstructure?

Line 185f: Define  $g$  (only defined in line 299).

Line 186: Please define the term "snowpack's effective density"

Line 189: Please define  $\zeta$ .

Line 203 – 210: First, you write that you are extending the model for mechanics but a few lines later you write "and thus it is neglected in the following." I cannot follow this thought. Please clarify.

Line 214 – 215: "Instead of following [...] closure for the source term" repetition of line 202. I suggest to add the references mentioned in line 215 to line 202 and delete 214-215.

Line 244: What do you mean with "necessary accuracy"? Please add a sentence what the necessary accuracy for the scenarios is.

Line 245: I suggest to add "using a 1d snow column" at the end of the sentence "[...] scenarios considered in the paper."

Line 247: "In that situation". Which situation do you mean with "that"? What is a complex geometry in this context? 2d/3d?

Line 252: For the interested reader, it would be helpful to add an example reference for the use of a second order Strang splitting.

Line 275: You only explain the usage of a Lagrangian approach in this line but already use the term before in line 237. I recommend moving this explanation to an earlier line.

Line 301: What about Crocus? Please add reference here.

Line 313: "within"

Line 323: Define  $\alpha$ .

Figure 2: Nice and helpful overview. I suggest inserting the names of Calonne, and Hansen and Folien in the boxes of the approaches and the equation numbers used to give the reader a quick overview.

Line 347: Figure appears in manuscript before it is mentioned in the paper.

Line 349: What is the minimum time step for the output? Does it also vary?

Line 351 – 356: Already in Figure 2. Please bring both information together in Figure 2 (see also comment about Figure 2).

Line 360: I recommend deleting "(Sect. 4)"

Line 383: "The densities are in the range of [...]" For which regions/ type of snow is this the case?

Line 384: Correct "over over".

Figure 3: Why do you choose these densities? Why does your layer have equal thickness? Representative for what region? Why do you use the values for ice volume, representative for what? Any reference for the used values?

Line 392: I recommend changing "As the first step" to "first"

Line 394: "Furthermore, the vertical velocity varies less in the upper layer than it does in the lower layer." Misleading formulation, difficult to understand on first reading. Please clarify: in comparison of the same time step or between/within time steps?

Line 397: Does it increase at all in the upper layer? I can only see the thinning of the snowpack but no colour changes in the upper layer.

Line 398: "the extent of the upper layer decreased only slightly with time", how many cm at the end?

Figure 4: It might help the reader if you mark the upper and lower layers at least on the y-axis, as you write about the upper layer and the lower layer e.g. line 394, line 397.

Line 420: You mention that this is explained in detail in Schürholt et al. but a short summary would be helpful. 1 to 2 sentences e.g. why, also in reality? Where observed? Why peak, why peak between layers?

Line 421 – 426: Very interesting. It would be valuable if you could discuss this further and in relation to reality. What is expected in reality? Why is the peak 4 times higher?

Line 430: In equation 23 und 24,  $E_c$  and  $E_t$  are used, but only one number is given here. The meaning of this is unclear. Shouldn't there be one number for  $E_c$  and one for  $E_t$ ?

Figure 6: It would be valuable for the work if you also add a plot c) for the temperature gradient for case 5. Perhaps a plot d) for vapour density gradient for case 5 over time would also be beneficial. You write about both in your text.

Figure 7: (a) Where is the dashed line? If it coincides with the solid line, please change the visualisation so that both lines are visible.

Figure 8: Not mentioned in the text.

Line 441: I recommend adding at the end of the sentence "for case 7 of Table 2, which refers to the fully coupled process in combination with dynamically varying viscosity".

Line 443 – 444: Please add a discussion why this is the case.

Line 449: "As discussed before" please add section number.

Line 452: I suggest adding "Figure 10 (a) [...] for case 8".

Line 458: "decreases in height". I recommend providing numbers from what height to what height or by how many cm?

Line 456: You use alternately "paper, study and article" in your manuscript. I recommend deciding on one term for the whole manuscript.

Line 531: "in the respective section" Please add section number.

Line 537: (e.g. Vionnet et al. (2012)

Section 5: In your summary and conclusion section, you use about one page to write about future work and challenges. I recommend moving this part to a separate section called e.g "Future work and challenges" before the summary and conclusion section.

Line 561: "Audet and Fowler, 192 please remove brackets.

Line 607: Define pa.

Figure D1: Why are different times shown here than in the other plots (15h, 32 h, 48h vs. 0 h, 16 h, 48h)? I suggest making the graphic square.

Line 729: 2021.