

Interactive comment on “Snow farming: Conserving snow over the summer season” by Thomas Grünewald et al.

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First we want to thank J. Garvelmann for his constructive review and his good suggestions. We are answering his comments in the following, for clarity we repeat the original comment (C) and answer (A) afterwards:

Major comments:

C: The authors nicely describe the background and the motivation for snow farming. However, there is missing the clear formulation of the motivation for the study and the most important research questions that the study will address at the end of the introduction section.

A: Thank you for this hint we add the following sentence at the end of the Introduction

C1

section: “A rising number of expertise on snow farming has been requested at SLF in recent years. This motivated us to (i) provide a review on current snow farming praxis (ii) to perform a detailed field study on snow farming and (iii) to describe and evaluate the model used for snow farming expertise by the SLF. “

C: The methods are described clear and understandable. On page 7 (lines 24+25) the authors mention that they used the model SNOWPACK for the simulation of both snow heaps. However, there are only shown results from the Flüela snow heap in the results section later. I recommend showing also results from the Martell site for completeness of the study.

A: This is principally right, we focus on the Flüela data and only provide the most important information for Martell. The reason is that the principal findings from both sites do not differ much: Adding more Martell details would not provide new findings and the added value would be very small. For readability we therefore decided to focus on the Flüela results and to only show the most important values for Martell (in brackets). This is also described in the text.

C: There are sentences that should be moved to the introduction section. The sentence on page 7, lines 25-27, for example, describes the motivation for the modeling of the snow heaps. Or the sentence on page 8, lines 22-25 describes the motivation for the sensitivity analysis.

A: It is right that these sentences would also fit to Introduction content-wise. However, Introduction already contains this information. We deliberately repeat this information in section 2.4 for readability and clarity.

C: The simulation of the stored snow was carried out using the one-dimensional snow cover model SNOWPACK. However, the authors mention twice that the use of a spatial distributed snow model such as Alpine3D for example would have been more appropriate to model the snow piles. The first thought while reading the manuscript is, why such a model was consequently not used in this study? Please provide an explanation

C2

for this.

A: We see the point of the reviewer. It is right that using a distributed model such as Alpine3D could account for spatial heterogeneity (most important: insolation depending slope and aspect) but spatial distributed input information (e.g. information on the local wind field, spatial variability of the cover material) required for such more sophisticated analysis was not available. This uncertainty of the input data would probably be larger than the resulting spatial variability of the results. Moreover, as insinuated in the new sentences in Introduction, SNOWPACK is the model that has been used for snow farming engineering projects by the SLF so far. Such projects aim to provide rough estimations on expected mass losses for specific sites and covering methods. Such requests can well be answered with a 1D model (SNOWPACK). Setting up and running SNOWPACK and analyzing the results is easier and more straight forward and therefore more cost effective. Our paper shows well, that SNOWPACK is well capable for this purpose. For detailed analysis of processes and their spatial variability, we definitively aim to apply Alpine3D in future (projects to come). This will be interesting from a scientific perspective.

C: The simulation was carried out just for one point of the snow heaps, the point with maximal HS. Please indicate those points in figure 5 and 6. Why was the simulation not carried out for multiple points at the snow heap?

A: The points are now indicated in Fig 5 and 6. As explained before, the added value of multiple point simulations would be rather small.

C: Another concern is related to the used parameters shown in the results section. Why are the results shown for snow height? You have height/volume and density. Why are the simulations not carried out for SWE? Another possibility would be to calculate (and simulate) total snow mass and mass loss in kg. For the TLS measurements providing snow volume and the measured snow density it would be simple to present some quantities of total snow mass loss ect. This would also be possible for the simulations

C3

since the calculation was carried out for a quadratic area of 1 m² as described on page 13. Please provide the results for actual snow mass or provide at least a detailed discussion why the results are only shown in snow depth.

A: Generally it is true, that snow mass or SWE is the quantity that would be most interesting in snow farming. However, snow height is the quantity that is measured by laser scanning. Snow height and volume can be measured very accurate. Contrary, only few density measurements required to calculate SWE or mass from HS were available, adding some uncertainty for the related quantities. Moreover, snow depth is a more concrete quantity for practitioners and laymen (who are also addressed by this paper). We therefore decided to stick with snow height/volume in Sec 3.3. Furthermore, the influence of densification is already discussed in detail, most important findings (relative losses) are also provided for SWE and simulation results are also shown (e.g. Fig 10) in SWE.

Minor comments: A: we adapt most suggestions of the reviewer in the text and only answer to non-technical comments:

C: Figure 1 and 2: The authors could think about providing a map for each study site showing the surrounding terrain.

A: We have considered showing such a map. However, considering the already large number of Figures (11) and also that the character of the surrounding area can already be seen in Figs. 1 and 2 we decided against showing additional figures.

C: Table 2: Needs a better explanation in the table caption

A: The table and the caption have been changed such that the initialization should be clearer now.

C: Page 8, Line 5ff: Is this assumption really realistic that the properties of sawdust and the mixture of sawdust and wood chips are similar? I would expect that the porosity is different ect.

C4

A: This is a reasonable doubt. From our investigations we think that the difference between the materials is much smaller than the uncertainty in the estimations of these properties and the spatial variability of the cover material (which is especially large for the mixture of chipped wood and saw dust). To test the effect of porosity (and therefore water storing capacity) we performed some model runs with varying grain sizes of the covering layer. Increasing the grain radius (from 0.1 mm to 1 mm) by a factor of 10 did not reveal any difference in the final mass loss. Only much larger grain sizes (3 mm) increased mass loss slightly. Wood chips of that size (or even bigger) exist in the Martell covering Material, but the finer particles clearly dominated. Moreover, from laboratory measurements of small samples from both heaps we found nearly identical dry densities. We therefore believe that the assumption of same properties of the covering material is appropriate. We include a corresponding sentence in the text.

C: Figure 3: You are showing net longwave, right? Please add this info. It would also be very helpful to indicate the exact dates when the snow heaps were covered with the isolating material and when it was removed. Please provide the same figure for the Martell site as well

A: Yes it is net longwave. We will clarify this in the new draft. The figure for Martell is already in the paper (Fig 4). The heaps were covered from mid of April till 19 October in Flüela and from 19 May till 28 October in Martell. Snow was then immediately distributed to the tracks. We add this information in the Study site section.

C: Figure 5+6: The authors could also provide a figure with the fraction (in percent) of snow loss at the two snow heaps.

A: This is a good suggestion, but the added value is only small and we are therefore not showing an additional figure.

C: Page 14, line 9: You describe earlier that the model was initiated with 8,6 m. Please clarify

C5

A: 8.6 m is the height of snow without saw dust and 9 m is the height of the entire heap with saw dust cover. We think it is already clearly stated.

C: Page 15, line 2: Earlier in the manuscript you mention that snow density was 555 kg/m³. Please check.

A: 555 is the mean of the density measurements. 553 is the density used in the model. This density is calculated from the volume fractions of water, ice and void. The difference to 555 is attributed to rounding of these fractions to two digits.

C: Page 17: An explanation of figure 10b, 10c, and 10d is missing.

A: The explanation is later in the text (Page 18). A reference to Fig 10d will be added.

C: Page 18, Line 21: Please quantify this high correlation here.

A: We are not talking about a statistical correlation in that context. To clarify we change the sentence to: "This underlines the high impact of sawdust thickness on energy available for snow melt."

C: Page 18, Lines 7-9: This is hardly visible in figure 11. I recommend to recolor the sum of the individual energy balance components and change the color of heat of precip to black.

A: Figure has been recolored.

C: Page 22, Line 2: Please provide more information here.

A: We added the range of losses (12-50%) (based on an survey of several snow farming sites)

C: Page 22, Line 27: Please provide more information about operation costs. I think this is very important information here for interested readers

A: Right, so we added the following information which is based on the personal communication of the responsible persons (Norbert Gruber & Werner Putzi) of community of

C6

Davos: “Operational costs have to be evaluated for each snow farming project specifically considering the applied technical and logistical solutions. For example in Davos 15 CHF per m³ snow were estimated for the first snow farming project in 2008. Till 2016 these costs could be strongly reduced to about 9 CHF per m³ thanks to larger snow volumes stored and improved infrastructure and work flow. Investments for structural measures at the storage location are not considered in this calculation. Two thirds of the expenses were caused by the distribution of the snow along the cross-country track followed by the removal of the saw dust (14%) and material costs for saw dust (10%) , assuming a five year operational live-time (Norbert Gruber and Werner Putzi personal communication). Generally, it can be stated that snow production costs are minor compared to covering and especially distribution costs. “

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