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Interactive comment on "Optimization of over-summer snow storage at mid-latitude and low elevation" *by* Hannah S. Weiss et al.

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Weiss et al present a case study on over-summer snow storage (snow farming) at two sites in Vermont, US. Melt rates of two small snow piles were calculated from repeated high resolution snow volumes measured with terrestrial laser scanning (TLS). Meteorological parameters and temperatures in the covering layer were continuously measured. Moreover and they investigate the performance of different settings of covering materials (combination of wood chips, open-cell foam, rigid foam, blanket); It is shown that snow storage seems possible, even at such a low-elevation site. The novelty of the study is the high temporal resolution of the snow volume surveys (14 surveys over summer-season) and the detailed assessment of temperature gradients within the covering-material. Such data have not been presented before. Data and

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Discussion paper

results are generally presented nicely and are definitively worth publication in TC after a careful revision; some sections are unclear and need to be reformulated or enlarged (see below). Most important, I think that the large potential of the data set is not fully exploited: The high spatial (10cm) and temporal (about 2 weeks) resolution of the TLS data would allow a more detailed analysis (see specific comments). Considering the effort of the suggested additional analysis and the many smaller things to be changed I suggest major revision (could also be major minor revision);

Specific comments:

1) TLS section requires more detailed information (settings of device, accuracy, references)

2) Section 5.1 should be enlarged with an analysis on spatial and temporal variability of snow melt (TLS data).

Interesting questions to be answered are: How do melt rates principally vary spatially (e.g. depending on slope and aspect of the piles)? How does the type of covering material combination affect melt rates? (Compare the different areas) How does the spatially varying depth of the wood chips (known from first survey) affect melt? Addressing these questions would be very interesting and would substantially improve the impact of the paper.

3) Section 5.2 must be revised; Temperature alone cannot be used as criterion to judge covering material performance; TLS data could be used to analyze effects of different cover on snow melt;

4) Results should be related to earlier studies and other snow farming projects;

5) Many statements need to be rephrased for correctness and more clarity

More details can be found in the technical comments below.

Technical comments:

Abstract: should be a single paragraph. Remove line-breaks

p1 l 13: this statement “has never been attempted at low elevations...” is too rigid. There are some low-elevated places (e.g. Ruhpolding Germany, elevation 700m) that successfully operated snow farming for many years. Please formulate more carefully.

L 22-24: It is unclear how the two piles were covered and to which pile the mentioned rates of change refer; what is meant with “minimum rates of change”? I suggest to provide ranges and mean for the rates of change.

L25: replace “blackbody radiation” with “long-wave emission”

L32-33: “This warming... snow packs.” This statement requires a reference

L36 in that context it is unclear what is meant with “... by covering snow”. Please reformulate; moreover the current review paper of Steiger et al 2017 could be cited in that context;

P2 L1-3: there was only little research on snow making (from the science side) in the last decades; most of the innovation came directly from industry; This changed a bit in the last years when the public sector and science began to realize the importance of snow making and snow management and the challenges of climate change for the skiing industry; Examples for recent publications are Hanzer et al. 2014, Grünewald and Wolfsperger 2019 or Spandre et al. 2016;

L 6: why is snow storage safer than relying on weather conditions? Please be more concrete here

L8-14: For cooling people mainly used lake or river-ice; the cited reference (Nanegast 1990) also seems to refer to ice; snow was (and is still used) in some areas of Asia and Scandinavia. As formulated now, the paragraph is bit confusing; Please reformulate and be careful not to mix ice storage with snow-farming for winter sports as described in the end of the paragraph;

L14: snow storage is quite expensive (see Grünewald et al. 2018)

L16 Besides solar radiation, air temperature is most important for snow melt (see Fig 11 in Grünewald et al. 2018); precipitation is less relevant; why should evaporative cooling be higher in cold and dry climates? Evaporation is depending on the temperature gradient between surface and air, wind and wetness of the covering-layer.

L22 I suggest to point out the research gap and the novelty of the study here

L27 use J/kg as unit for energy instead of cal/g

L31 use long wave emission or long wave radiation instead of blackbody radiation

L34 Long wave radiation especially depends on surface temperature (Stefan Blozmann law: power of 4!)

L36 snow melt instead of snowpack melt

P3 L5 I am not happy about the formulation "high elevation"; if 1600 is high, what is 3000m? And: the latitude of Vermont (45°) was called "low" (P2 L17);" here a very similar latitude of 46° is called "mid"; this is not consistent;

L6 I suggest to write machine-made or technical snow instead of artificial snow

L6 remove "wet"

L8 write "Using a physically based model" instead of "thermal models"

L8/9 please clarify context: most effective means in relation to work/cost effort; deeper layers can safe more snow but the effort is higher

L11 write "capillary flow" instead of "capillary action"

Section 3: The section is very short. I suggest to merge section 3 and 4 to "Methods and settings" and then to introduce subsections; (e.g. study site, Weather stations, terrestrial laser scanning, snow density, insulation experiments...)

L30 what is the elevation of the site?

L33 What is the elevation of the station?

L 31-33: please also indicate mean temperatures not only minimum and maximum

L 34-36 USAD, NOAA, USGS > citation style is wrong; year is missing

P4 L1 please describe differences between the two sites (pile 1 and 2), e.g. shadow, slope . . ..

L5 provide a reference to snow density section

L5 provide more information on the properties of the plastic sheets (e.g. thickness, size, water permeability, thermal conductivity . . .) and for what reason they were used (I guess to reduce snow pollution as stated later); such information should also be given for the foam used in for the insulation experiments

L6 brackets are missing (Fig. 3)

L9 at which height above ground were the meteorological measurements performed?

L12 be more clear about soil temperatures: how many sensors? Where were the sensors? Where the sensors in the ground or in the covering layer?

L15ff this section requires more details: the dates of the scans should be provided, e.g. in a table; Also add a table with the technical specifications of the laser scanner; Was multi-station adjustment used for registration; why not? It is an easy approach to improve registration of the data; What is the accuracy of the data? Were data gaps (scan shadows) existing? How were they handled? If a direct accuracy evaluation of the data is not possible, at least references to earlier studies that assessed TLS accuracy in similar settings should be added, e.g. Prokop et al. 2008, Grünewald et al. 2010, Grünewald and Wolfsperger 2019;

L32 please add for how long the insulation experiments lasted; until end of summer?

L32 please state what kind of R (e.g. Pearson's correlation coefficient) is used

P5 Sect 5.1 Sum of precipitation should also be given; How were condition of the recorded summer season in relation to long term climate? Data from station COC described in Sect. 3 could be used to rate this summer;

L10-17: It is not clear which measurements are described here: the sensor below the piles or the ones next to the piles? Is there an explanation for the much larger T – variability for the 5 cm sensor at site 1 in relation to site 2? To which of the two sites does Fig 5 refer to?

L17-19 unclear: only measurements of one site (below pile or next to pile) are shown in Fig 5;

L24: add a reference to Fig 3 (after . . ."for pile 2.")

L25 use kg/m3 instead of g/m-3

L25-26 Where were densities measured (in which depth) obtained? Densification should be related and discussed in relation to the results of Grünewald et al. 2018 who showed an increase in density, both in time and in depth;

L26-27 "Relative to . . . (0.9g/cm-3)." Relating density to fresh snow is not meaningful in that context and could be removed;

L27: I do not think that this is an adequate explanation. Snow with a density of 500 kg/m3 should already be fully decomposed and rounded; Was the snow dry during density measurements? Or was there some liquid water content? Or did you identify ice aggregations resulting from refrozen water? What was the grain size in March?

L29: Please check the numbers: Considering the very similar melt rates of the two sites (Fig 7) the difference between 1.24 and 1.5 m3/d seems very high; is the removal of the 30m3 snow possible part of the melt rate?

L29-32 Discussing melt rates is the main focus of the paper; Please discuss them in more detail; Your data set should allow a much more detailed analysis! e.g. how do melt rates change in time and how does this related to meteorology? Do melt rates vary spatially? What is the difference between the two piles? What is the difference between sections with different cover material?

L32-37 possibly even the effect of the crevasses could be seen in the TLS data (e.g. local changes in melt rates?

P6 Sect 5.2. This section is pretty poor. It should be enhanced: a discussion and reasoning on the effects of the different covering types (properties of materials and how do they interact with snow and atmosphere is missing; Currently only temperatures are analyzed but this is not enough to judge performance of the different materials; The TLS data could be used to quantify and discuss if and how volume losses differ under different covering materials.

add references to the specific panels for Fig 4

L2 insulation efficiency is not only a function of T, e.g longwave emission or turbulent fluxes are not only depending to T but very relevant for the energy balance;

L12 the presented experiments used wood chips and a plastic planked not only wood chips;

L13-14 climate is not only a function of latitude and elevation; please rephrase

L 15 (fairbanksmuseum, 2019)) > remove bracket

L36 Provide more details on the PSD method; how does it work and what is its benefit? How is it interpreted? Add references;

P7 L6-9 This explanation is too simple: heat transfer is not simply depending on air temperature; surface temperature, cloudiness (longwave radiation) and wind (turbulent fluxes) are also crucial; See discussion of simulation results in Grünewald et al. 2018 and the sections about energy balance, and snow melt of the recent review paper of

Mott et al. 2018; these references and possible also other earlier work should be cited in context of the discussion;

L11 what is the “R-value”?

Section 7: Conclusions should be prolonged; Here all three research questions form the introduction should be shortly answered; an outlook on future research that might be useful to enhance our understanding on snow storage might also be added;

Figures

Figure 1 b) it would be nice if the list would be ordered geographically; Several sites are missing (see attached pdf; Reference: Wolfsperger et al 2018)

Figure 4: T fluctuation of the blue line is hardly visible; possibly change axis or figure dimension

Figure 5: Figure a should be enlarged vertically to improve readability; grids or vertical lines should be added; For humidity and radiation adding daily mean values as line could also help to improve readability; Legend: To which snow pile does the figure refer to? Ground temperatures below or next to pile?

Figure 6: Please add a legend relating colors to dates.

Figure 7: Why is the increase in volume from April 1 to May 1 for site 2 so much larger than for site 1? Was there such a big difference in volume of chips added? Are colors between the two panels possibly mixed? The huge melt rate drop on July 1 might be correct for Site 1 (blue) but not for site 2; Add a grid or horizontal lines for readability;

P9 L15 doi seems to be wrong

L22 and L 24 The papers are not cited in the text;

Having only checked few selected references I found three mistakes; I guess that there are more. Please check your citations and references carefully!

Best regards Thomas Grünewald

Mentioned Literature

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Please also note the supplement to this comment:
https://www.the-cryosphere-discuss.net/tc-2019-56/tc-2019-56-RC3-supplement.pdf

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