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Interactive comment on "Seasonal evolution of snow permeability under equi-temperature and temperature-gradient conditions" *by* F. Domine et al.

F. Domine et al.

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1 General comments

This is an interesting study of snow permeability seasonal evolution in two different regimes of snowpack metamorphism. The results regarding the influence of depth hoar microstructure on permeability/air flow are particularly interesting and I believe an important contribution to the body of work regarding these kinds of investigations. There are some instances where the manuscript could be clarified to help make certain points more readable, as noted below, and a very few

typos. I also think there are a few instances where the methodology and parameters being used need to be described, which I've noted below in chronological order.

We thank the reviewer for his/her positive appreciation of our work and have taken into account the numerous suggestions made - see details below.

2 Specific comments

My one main concern with respect to the scientific merit is the ET measurements, which seem to be very unrealistic. I think a stronger case for why these measurements are relevant or important is needed. I do think that it is an interesting comparison between the evolution and the deviations from the model results of the two metamorphic regimes, but this should be discussed in the introduction.

The reviewer has an excellent point. We will modify the end of the introduction and the methods section to better explain our motivation. Briefly, our ET snowpack is not meant to be a perfect substitute for a real natural ET snowpack. In particular, our ET snowpack can reach very low temperature, since in winter it is essentially at air temperature. Its interest is to provide a snowpack under conditions dramatically different from those of the TG snowpack, so that we can use the data from the ET snowpack to test more thoroughly SSA/density/permeability relationships and the performance of our snowpack model in predicting snow permeability.

3 Technical corrections

Abstract, line 34, This sentence is confusing on first reading, and I think because the idea of the depth hoar not being spherical is introduced rather abruptly. I

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would suggest rewriting to "Simulated permeabilities are up to a factor of two greater than measurements for depth hoar layers, which we attribute to snow microstructure and the aerodynamic properties of the snow crystals." If the sentence is left as is, an added description of the model using SSA to calculate permeability might help to make this easier to understand.

We propose to rephrase as "Simulated permeabilities are up to a factor of two greater than measurements for depth hoar layers, which we attribute to snow microstructure and its aerodynamic properties."

Line 38. I suggest making this into two sentences as it is a bit of a run-on, i.e. "Finally, the large difference in permeabilities between ET and TG metamorphic regimes will impact atmosphere-snow energy and mass exchanges. These effects deserve consideration"

The sentence will be cut in two as suggested.

Line 45. This sentence is slightly awkward, borderline not grammatically correct. I would suggest rewriting as, "One noteworthy consequence of these processes is the deposition of atmospheric particles such as sulphate and sea salt to snow, affecting the snow chemical composition."

Thank you for the suggestions. This sentence will be rephrased.

Line 68. This sentence is unclear, and should be written, "Equations have been proposed that relate permeability to other snow physical parameters. Shimizu (1970) relates permeability to snow grain size, r, and snow density ... .and is probably the most widely used" And I suggest citing some references after the first sentence, as there are several (i.e. Freitag et al., 2002; Horhold et al., 2009 among the more recent). I also would suggest adding a phrase describing r as being determined from hand lens measurements, to differentiate this r from the r determined from SSA in Eq. 4.

This sentence will be rephrased as suggested. Additional relevant references presenting such equations will be added and the variable r_{vis} will be introduced to describe the visual grain size.

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Line 73. "offer" should be "offers" or change "work" to "works" and leave offer singular

"Work" will be replaced by "works".

Line 86. "during" should be "due to"

We will not modify the text here. Indeed, snow metamorphism is not *causing* changes in snow permeability, but it is rather the transformation of all physical properties of snow related to its microstructure (including permeability) which is referred to as metamorphism, as a single term summarizing these transformations.

Line 91. In order to clarify that the measurements were made by Taillandier, this sentence could be written as "against in-situ collocated measurements of K, SSA and rho which are presented in Taillandier et al. (2007) and Taillandier et al. (2006) ..."

Permeability measurements were not reported in any of these two articles. This sentence will be rephrased for better clarity.

Line 101. This sentence is confusing, and I would suggest writing as "The site was in a clearing with a low wind setting which resulted in a laterally homogeneous snowpack ..."

The sentence will be rephrased with a link to the observations reported in Taillandier et al. (2006).

Line 101. What is the typical wind speed of the area ?

The typical wind speed at 3 m height was below 2 $\mathrm{m\,s^{-1}}$ and the maximum wind during the study was 4.5 $\mathrm{m\,s^{-1}}$, reached in early January.

Line 104. Because only one temperature is mentioned in the previous sentence (-40deg C), I suggest writing the next sentence as "The low air temperature, combined with". The word "to" should be changed to "with" to make the sentence grammatically correct.

Both changes will be made following the suggestion of the reviewer.

Line 116. What is the range of the temperature gradients? I think it would be helpful to state that here.

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This information is mentioned in Taillandier et al. (2006). Briefly, the maximum value is 198 K/m in the Fall, decreasing to 20K/m in Spring due to warming and thicker snowpack.

Line 125. This sentence is awkward. I suggest rewriting as, "Even though the wind was never strong enough to cause saltation at the ground level ..."

The sentence will be rephrased as "Even though wind was never strong enough to cause saltation of surface snow".

Line 137. The acronym CRREL should be defined.

"CRREL" will be replaced by "U.S. Army Cold Regions Research and Engineering Laboratory (CRREL)".

Line 143. What is the range of pressure differences measured? Line 145. Even more importantly, what is the range of flow rates measured?

Such information will be stated in the revised manuscript, with a reference to Jordan et al. (1999). **Line 157. This sentence is awkward, and I suggest, "The main improvement over the previous-stand along version of Crocus (ref.) is that the snowpack ..."**

This will be modified as suggested by the reviewer.

Line 162. By "ground surface," do the authors intend "snow surface" ? It should also be "below the ground (or snow) surface"

"Below ground surface" will be replaced by "below the ground (soil) surface".

Line 163. Should be "imposed on" not "imposed to" This section is confusing in that the description of the model set-up is jumping between the ground and table model inputs.

The text will be modified to remove this possible ambiguity.

Line 175. What does the word "diagnosed" refer to ? Is it the modeled or computed properties ?

The term "diagnosed" will be removed from the revised manuscript.

Line 177. There is either a missing closing parenthesis at the end of the citation, or if citation formats are changed, there is an extra parenthesis.

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This error was already fixed in the online version of the Discussion article.

Line 183. "increase" should be "increases"

This will be modified as suggested by the reviewer.

Line 183. This phrase is awkward, I suggest "to phenomenologically represent the impact of snow metamorphism" or something along those lines.

This part of the sentence will be removed for improved clarity of the revised manuscript.

Line 185. What do the variables Tfus and T represent? And what is the definition of alpha sub eta? Or is it just an empirical fit?

The variables will now be described explicitly in the revised manuscript. α_η is an empirical parameter.

Line 187. "To overcome unrealistic hampering of snow compaction ..." is awkward, and a little unclear. I would suggest something like, "In order to prevent the model from unrealistically computing low snow compaction due to sustained extremely low temperature conditions ..."

This sentence will be rephrased as suggested by the reviewer.

Line 199. ERA-Interim should be defined and briefly described.

The reference Dee et al. (2011) provides a detailed description of ERA-Interim. The term "meteorological" will be added to the term "reanalysis".

Line 200. SUFEX/ISBA-Crocus should be defined and briefly described.

The model is introduced earlier in the manuscript. Here, "SURFEX/ISBA-Crocus" will be replaced by "Crocus" for consistency with the rest of the manuscript.

Line 203. The acronym LARS should be defined maybe in line 199 when the study site is introduced as being at LARS

The acronym will now be introduced when the Large Animal Research Station is first introduced.

Line 210. The impact of the altitude difference should be specified (maybe even just the percent differences) so that the reader can determine if it is insignificant.

The temperature difference is 0.85 K. The corresponding change in precipitation phase leads to a variation from 83.3 % snow precipitation at the altitude of the ERA-Interim

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point to 82.0 % at the LARS altitude, while the total precipitation remains the same. In terms of snow simulations, for example this change induces a mean variation of 1.6 $\pm$ 2.2 cm for simulated snow height during the measurement period, which is indeed considered insignificant given the number of potential other errors affecting the snow simulations.

Line 211. "twice higher than" should be "twice as high as the in-situ data"

This will be rephrased as suggested by the reviewer.

Line 229. "stratigraphies" isn't commonly used, but instead "stratigraphic layers" is more commonly used.

"Stratigraphies" will be replaced replaced by "stratigraphic profiles" throughout the revised manuscript.

It is also a little confusing what the stratigraphy is from, the samples or the pits?

We are not sure to perfectly understand this question, given that all samples referred to here were taken from stratigraphic investigations.

Line 234. As above, "stratigraphies" in not in common usage

"Stratigraphies" will be replaced by "stratigraphic profiles" throughout the revised manuscript.

Line 240-244. This section is slightly confusing because it is not always clear that the table snow is being referred to in the plots, i.e. it might be helpful to specify that "The results for the table snow in Figure 3 show ... " and then, the rest of the sentence is hard to follow, only because "towards the top" is vague, so perhaps finishing the sentence with something along the lines of, " ... a decreasing trend in the top 20-30 cm of the density profile." Also, the density trend should be increasing, or at least it appears to be increasing at the top in the figure. Or is this referring to the decrease in density at the bottom 10-20cm of the profiles ? In any case, this is confusing and should be sorted out.

A clearer distinction between table and ground snow observations will be made by splitting the section in two more distinct paragraphs. We believe this will remove the confusion identified by the reviewer. Additional modification will be made to further

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clarify this section.

Line 256. The phrase "on the contrary" is awkward and should be deleted.

"On the contrary" will be replaced by "In contrast".

Line 258. This first sentence is confusing and/or grammatically incorrect. I suggest, "The present data can be combined with SSA, density and permeability measurements to test the relationship ..."

The sentence "The present data, which combine SSA, density and permeability measurements can be used to test the relationship of Calonne et al. (2012)" will be replaced by "The present data, which combine colocated SSA, density and permeability measurements can be used to test the relationship between these variables presented by Calonne et al. (2012)"

Line 262. "nor" should be "not"

This will be changed as indicated by the reviewer.

Line 296. The sentence should be written, "The model illustrates the contrasted thermal field within the snow between the ground and table simulation well."

This sentence will be rephrased to "The model illustrates well the contrasted thermal field within the snow between the ground and tables cases".

Line 319 and elsewhere. The reported permeability values are missing the "x" term before the exponential term, i.e. 200 x 10^{-10} is written as 200 10^{-10}.

This will be fixed as suggested by the reviewer.

Line 320. Awkward as written. Maybe, "On the contrary, values from the snow on the ground keep increasing up to about ..."

"On the contrary" will be removed from this sentence.

Line 322. "follows" should be "follow"

This will be changed as suggested by the reviewer.

Line 347. "within" should be "with"

This will be changed as suggested by the reviewer.

Line 348. Actually, field measurements of the same type and same sample of snow are generally within 10-20% (depending on the instrument, and possibly

instrument user), so this bias is high.
This statement refers to the repeatability of measurements for a given snow sample, which does not encompass the whole range of measurement uncertainty, not only because of the variability of snow properties within the (visually apparently) same snow layer, but also because handling the sample and placing it in the measurement instrument will cause further uncertainties. As an example, it has been reported that the typical uncertainty on snow density measurements is on the order of 10 % (Conger and McClung, J. Glaciol. 2009). It seems hard to believe that permeability measurements of seasonal snow samples (firn samples are not dealt with here) could be accurate within 10 to 20 % in general. Given the relatively low number of samples, spanning a wide range of snow types and sampling conditions during our field campaign, a complete analysis of peremability measurement uncertainty was beyond the scope of this study. Here again, this study has to be viewed as a first attempt to document the time evolution of the permeability of seasonal snow under contrasting thermal regimes, leaving for further studies more in-depth assessments and refinements of the results obtained here.
Line 350. What are the sources of error in the simulated data?
Results from numerical modeling of the snowpack includes a large number of error sources such as : errors of the meteorological driving data, errors of the representation of physical processes in the model (simplifications, uncertain model parameters, ...) and uncertain physical variables describing the environmental setting (such as ground properties, ...). This will be added at the end of the corresponding paragraph.
Line 368. "that" should be "than"
This will be changed as suggested by the reviewer.
Line 376. "are" should be "is" or you should change "difference" in line 375 to "differences" to make verb and subject agree
"Difference" will be changed to "differences"
Line 384. There is either a missing parenthesis or an extra parenthesis depending on how the references are formatted.

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The sentence will be fixed.

Line 389. "equations (3)" should be "equation (3)"

This typo was already fixed in the online version of the Discussion article.

Line 391. "coupled to" should be "coupled with" and "result" should be "results"

This sentence will be fixed.

Line 395. I think the rest of this paragraph is speculation. As there are no measurements or model results to support it, I think the discussion of anisotropy and horizontal permeability should be deleted. (the last sentence is fine comparing TG and ET snow, and that is interesting).

We do not see traces of speculation in this part of the article, but rather a summary of some of our findings (corroborating and corroborated by other previous investigators) which are put in a wider perspective.

Line 400. Similarly, I think the last paragraph brings up some very interesting points, but does not belong in this section of the paper, since it again is speculative and not supported by measurements. It maybe could go in the intro/background as motivation to do this sort of work, or this section of the paper could be introduced as "some possible implications of the effect of temperature gradient metamorphism on snow properties are... " or this paragraph should be deleted.

We believe that it is absolutely normal that the Discussion section brings some speculation, as long as it does not form the majority of its body, which is not the case here.

Line 421. This sentence is slightly awkward, I suggest deleting the "Then" in front of the sentence.

"Then" will be deleted in the revised manuscript.

Line 423. The simulated results are reasonable for the ET snow, as shown in table 2, but they are not as reasonable for the ground snow. You should specify this in the conclusion.

This fact is already reflected in the last sentence of the conclusion.

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Table 2. I think "n" should be defined as the number of samples measured
This will be fixed as suggested by the reviewer.

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