Report on the revised version of paper tc-2015-158: Metamorphism during temperature gradient with undersaturated advective airflow in a snow sample

P. P. Ebner, M. Schneebeli, and A. Steinfeld

The authors have improved the original version of the manuscript, leading to a better presentation of the experiments realized and of the subsequent scientific argumentation. However, the paper really needs an additional revision before it can be published. In particular:

-I. Some of my previous requests have not been addressed adequately. It is especially the case of requests #3.x concerning the post-processing and reliability of the data:

3. Data post-processing and reliability: The experiment is really interesting, but some "unusual" results obtained need to be checked, clarified or discussed. It is in particular the case of:

3.1. Some erratic translations or changes that can be observed in the image series (see the enlarged version of Fig. 2 in supplementary materials). Has each image that constitutes Fig. 2 been spatially repositioned thanks to adequate references? The beginning of the series ota3 is especially problematic. For most series, some slight but persistent downward translations are observed and should also be commented. See e.g. comment 4862/Fig 2.

3.2. Fig. 3, which is a bit difficult to "read" (no classical rounding or TG effect) and exhibits some post-processing artifacts. See comments 4863/Fig. 3 for suggestions.

3.3. The ota1 series, which does not show any increase of the vertical component of its conductivity when submitted to a TG only. At least a comment should be written on this topic. See comment 4852/27-4853/2.

3.4. Ideally, a characterization of the structural anisotropy of the snow samples would be appropriate. See comment e.g. 4850/7-8.

→ At least, point 3.1 should be accurately addressed before publication (see specific comments 91-92, 118-119 and 416).

-II. I am now also concerned with some of the physical interpretations of the experiments, which do not seem sufficiently convincing to me. In particular, some conclusions of the paper (e.g. about the "preference" for deposition to sublimation [lines 253-255], or the limiting mechanisms occurring at microscale [lines 176-180]) are based on the fact that little effect can be observed on the snow microstructure in the described experiment as compared to that of Ebner et al 2015b. However, as mentioned by the authors themselves, this fact can just been explained by the settings of the present experiment, where TG and air flow counteract.

Actually, the authors just mention 2 TG and air flow configurations in their paper but 4 important configurations are possible:

1. air mainly **supersaturated** with respect to the entire sample (typically, Td = -12.5 when the sample is between T_base = -12.5 and T_top = -14) and TG and air flow acting in the **same direction** (Ebner et al 2015).
2. air mainly **undersaturated** with respect to the entire sample (typically, Td = -14 when the sample is between -14 and -12.5) and TG and air flow acting in the **opposite direction** (this paper).
3. air mainly **supersaturated** with respect to the entire sample (typically, Td = -12.5 when the sample is between T_base = -12.5 and T_top = -14) and TG and air flow acting in the **opposite direction**.
4. air mainly **undersaturated** with respect to the entire sample (typically, Td = -14 when the sample is between -14 and -12.5) and TG and air flow acting in the **same direction**.

I am puzzled by the fact that the authors, by comparing cases 1 and 2, try to reach conclusions about local sublimation and deposition processes in snow. However, these conclusions might only be achieved from a precise comparison between 1 and 4 (or also 2 and 3). It should be also noticed, that for case 2 and 3, TG and air flow effects clearly counteract and an increased observation time (or increased resolution) would probably be necessary to infer reliable conclusions on the physical mechanisms involved. See also comment 162-163.

→ Complimentary experiments, or at least, complimentary explanations seem mandatory to assert some of the authors' conclusions.

Specific comments:

15-16: *The temperature gradient in the sample was around 50 K m-1 at maximum airflow velocity.*

→ Is really TG dependent on the airflow velocity? If not, I suggest modifying the sentence to prevent any misinterpretation.

→ Giving the quantitative value of the maximum airflow in L/min would be more informative.

16-20: *The sublimation of ice for saturated air flowing across the snow sample was experimentally determined via changes of the porous ice structure in the middle-height of the snow sample. Sublimation has a marked effect on the structural change of the ice matrix but diffusion of water vapor in the direction of the temperature gradient counteracted the mass transport of advection. Therefore…*

These sentences are difficult to catch for a reader who tries to understand the principle of your experiment. Here is a suggestion: "Changes of the porous ice structure were observed in the middle-height of the snow sample. Sublimation occurred due to the slight undersaturation of the incoming air into the warmer ice matrix. Diffusion of water vapor opposite to the direction of the temperature gradient counteracted the mass transport of advection. Therefore…"

19-20: *diffusion of water vapor in the direction of the temperature gradient*

Strictly speaking, this sentence is wrong: from the Fick's Law, the water vapor diffusion occurs in the opposite direction of the temperature gradient (j = -k **grad** P = -K **grad** T). Actually, in the whole paper, there seem to be a constant mistake with the direction of the temperature gradient (respectively, the vapor pressure gradient), which actually is in the direction of the growing temperature (respectively, growing vapor pressure). This has, of course, no impact on the general meaning of the paper but it needs to be corrected for a sake of clarity. Please check the whole text and figures, especially Fig. 1 (see also comment 412/Fig1).

34-35: *Various airflow conditions in a snow sample occur, namely: isothermal airflow, temperature gradient along the flow direction, and temperature gradient opposite to the airflow (Fig. 1).*

Please check these lines according to comment 19-20.

56-60*: Albert (2002) suggest that condensation of water vapor will have a noticeable effect on the microstructure of snow using airflow velocities, vapor transport and sublimation rates calculated using a two-dimensional finite-element model, which is also confirmed by a 3D phase-field model of Kaempfer and Plapp (2009).*

Actually, Kaempfer and Plapp (2009) did not consider any airflow in their 3D phase field model, while Albert (2002) did. Please change the way the citation is introduced to make it clearer to the reader.

91-92: *A linear encoder with a resolution of less than 1 voxel was used to verify that the scans were taken at the same position.*

From Fig. 2, it is obvious to any reader that this method failed to provide the same region of interest with time. As pointed out in my preceding review (see general comment 3.1 and comments #17-4850/3-4 and #22-4862/Fig 2.) large and erratic vertical translations (reaching sometimes about 50 voxels) are observable. Some images are even not recognizable from one step to another (e.g., ota3, 30hours), and this has potential impacts on the evolution of the provided numerical results (porosity, SSA, conductivity…). The authors should really ensure the data they provide are reliable. They can just suppress all erroneous (or "suspicious") data from their dataset, or choose to numerically correct the image position as it is usually done in tomographic time-lapse imaging. However, providing obviously erroneous (or poor quality) data is not acceptable in a journal like TC.

118-119: *The change of structural change "ota 3" at 30 h is due to an error in the scan.*
See comment 91-92.

162-163: *As thermally induced diffusion was opposite to the airflow gradient, a backflow of water vapor occurred and the two opposite fluxes cancelled each other out.*
I basically agree with this sentence, but is it fully compatible with the fact that the snow evolution is completely independent of the flow velocity? To my understanding, the TG is always fixed: if the opposite fluxes cancel out each other for a low velocity e.g., the airflow effect should be dominant as it increases. At least some comments and explanations should be added to the text.

167: *diffused along the temperature gradient*
See comment 19-20 → "diffused along the opposite direction to the temperature gradient"

176-178: *Our results support the hypothesis of Neumann et al. (2009) that sublimation is limited by vapor diffusion into the pore space rather than sublimation at crystals faces.*
Why? Is it only justified by the lines 178-180 (in that case, suppress the word "also" in these lines), or by other reasons?

178-180: *This is also supported by the temporal evolution of the porosity (Fig. 4 b)) and the SSA (Fig. 4 c)), as no velocity dependence was observed and the structural changes were too small to be detected by the micro-CT.*
See general comment #2. Complimentary experiments, or at least, complimentary explanations seem necessary to justify the authors' conclusions.

214-216: *The model by Neumann et al. (2009) does not consider the influence of a temperature gradient and the additional vapor pressure gradient was not analyzed.*
It is important to specify that point. But is it realistic to draw definitive conclusions from the comparison between a TG experiment and a model that does not really account for the important specificities (TG) of the experimental conditions?

232: *This indicates that advective cold airflow opposite to a temperature gradient…*
→ "This indicates that advective cold airflow along a temperature gradient…"
(or "This indicates that advective cold airflow opposite to the TG-induced vapor diffusion…")

232: *...and an open system…*
The meaning of this wording and its implications is difficult to catch without any additional explanations.
Please consider adding a more detailed comment such as your private response to comment #20-4852/27-4853/2

233-234: *the increase in thermal conductivity usually observed by temperature gradient metamorphism (Riche and Schneebeli, 2013).*
To my knowledge, Riche and Schneebeli (2013) do not report any increase in thermal conductivity during TG metamorphism. Citing e.g. Löwe et al., 2013 (Fig 4) or Calonne et al., 2014 (Fig. 6) might be more appropriate.

253-255: *The kinetic phase-change from gas to solid is preferable as energy is released compared to solid to gas where energy is required, thus leading to more water molecule deposition than water molecule sublimation.*
This sentence still does not make sense for me (see previous comment #16-4850/16-18). Again, I suggest removing it (or justifying it with proper argumentation, references, etc).

405: please specify the sizes of the volumes used for the computation of each property (7.2 x 7.2 x 7.2 mm^3 in all cases?)

406: *obtained by opening-size distribution* → "obtained by an opening-based morphological operation"

412/Fig1: The direction of the arrows for temperature and vapor pressure gradients should be changed in the opposite direction. Arrows corresponding to the direction of the vapor diffusion (effect of TG) could be added (j = -k **grad** P = -K **grad** T) to help the reader.

416/Fig 2: see previous comment #22-4862/Fig2 and current comment 91-92.

423/Fig 4 (a to d): to update according to specific comment 91-92.

Technical comments or suggestions:

35-38: *Under isothermal condition, the continuous sublimation and deposition of ice due to higher vapor pressure over convex surfaces and lower vapor pressure over concave surfaces, respectively (Kelvin-effect).*
A verb seems to be missing in this sentence: *due* → "is due" (?)

63: *dynamic* → dynamics

83: *the strength* → its strength

88: *18 μm^3* → 18 µm
(or 18 x 18 x 18 μm^3)

123: *ice grain* → ice matrix
(or ice grains)

124: *ice grain* → ice surface
(or ice grains)

150*: in the pore* → in the pores

178: *crystals faces* → crystal faces

192: *by (Neumann et al., 2009)* → by Neumann et al. (2009)

260: *under isothermal conditions Kelvin-effect…* → under isothermal conditions, Kelvin effect…

263: *whistler-like* → whisker-like

269: *and seems to* → and seem to

403: *ice grain* → ice grains

References

Calonne, N., F. Flin, C. Geindreau, B. Lesaffre and S. Rolland du Roscoat, 2014. Study of a temperature gradient metamorphism of snow from 3-D images: time evolution of microstructures, physical properties and their associated anisotropy, The Cryosphere, 8, 2255-2274, doi: 10.5194/tc-8-2255-2014.

Löwe, H., Riche, F., and Schneebeli, M.: A general treatment of snow microstructure exemplified by an improved relation for thermal conductivity, The Cryosphere, 7, 1473–1480, doi:10.5194/tc-7-1473-2013, 2013.