Authors’ reply to referee comments RC2

We thank very much Reviewer 2 for the comments that help improving the manuscript. Please find below our point-by-point replies in green color.

General comments

The paper by Bouvet et al. discusses two laboratory experiments where snow is put under a temperature gradient typical for arctic conditions. The changes in snow structure are mainly analysed by micro-tomography. Similar experiments have been conducted since 2004 by other authors. Using humidity sensors, an attempt was made to measure relative humidity inside the samples. The presentation of the data is sufficient. However, the data can not be publicly assessed, and the deposition of the data in a repository is now a scientific standard.

In the revised version of the manuscript, we will provide the data obtained from our work as .ods files in the supplement.

As observed by others, snow sublimates at the warm side of temperature gradient experiments, forming an air gap (already observed by Nakaya in the 1950'ies). Such an air gap immediately caused the thermal conductivity to be reduced to the one of air, and the initially vertical and parallel heat flux became distorted as the samples were surrounded by higher conducting plastic. As much as the reviewer could see, this fact was not taken into account (e.g. by numerical simulations) for the interpretation of the structural evolution of the snowpack.

The temperature field of the snow layer in Experiment B was simulated using the software COMSOL to evaluate the effects of the plastic sample holder and the polystyrene layer. The simulation of the initial stage of the experiment is presented for two setups, with and without the underlying polystyrene plate (Figure 2.c in the paper). The simulations of the temperature field at the end of the experiment with an air gap of 3 mm height is shown in the figure below. We see that the temperature field is slightly more perturbed by the plastic holder with the air gap than without. Without air gap, the horizontal gradient represents 10% compared to the vertical one, with air gap, this ratio rises to 12.6%, which we still consider small. In addition, we stress that the effect of the plastic holder on the temperature is observed right next to the side of the holder and vanishes while moving towards the center; tomography was performed on the snow volume located in the center of the holder only.
As suggested by Reviewer 2, the new version of the manuscript includes a comment on the simulations of the temperature field with the air gap in Section 2.2. It now includes “In addition, Figure 2.c shows that the presence of the plastic cylinder does not disturb significantly the temperature field and that non-vertical gradients represent 10% compared to the vertical one. Similar results are observed when simulating the end of the experiment with an air gap (12.6%).”

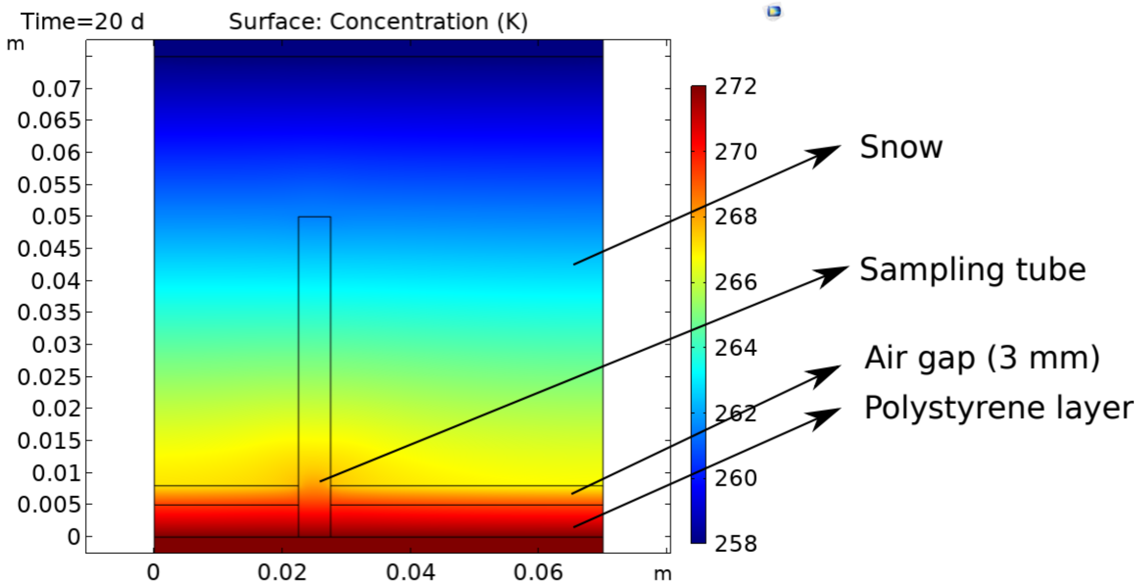

Figure 1. Numerical simulations of the temperature field for the snow layer at the final stage of Experiment B considering an air gap of 3 mm height.

The interpretation of the temperature and humidity profiles is consequently misleading. Without considering the non-vertical heat fluxes, no valid conclusions are possible. The sections "Results" and "Conclusion" must be rewritten and re-interpreted, considering a heterogenous temperature gradient and heat flux.

This comment might be the result of a misunderstanding of our experiments. We present two experiments, Exp. A and Exp. B, that differ in their set-up. Temperature and humidity were measured only in Exp A and not Exp B. The sampling method, to collect snow for tomography, was different in both experiments. Plastic cylinders were initially buried in the snow layer for further sampling in Exp B but not in Exp A. The latter followed the standard snow sampling procedure. Hence, the temperature and humidity profiles in Exp A are not affected by the presence of plastic cylinders as there was none. Concerning Exp B, as explained in the comment above, non-vertical heat fluxes related to the plastic holder were insignificant compared to the vertical ones and concentrated right next to the holder's sides. Besides, Exp B focused on the analysis of the air gap formation that was consistently observed everywhere at the bottom of the layer, inside and outside of the sample holders.

Specific comments

No details and data are given on how the humidity sensors are calibrated at below zero-degree conditions. Calibration before and after the experiment would have been necessary to have valid data.

Additional information on the calibration of the humidity sensors were included in the new version of the manuscript, which reads: "The SHT25 sensors are marketed with a humidity calibration at ambient conditions (~ 20°C and ~ 50% RH) and present large offsets when placed in cold and humid conditions, up to 7% RH. A calibration was conducted by placing the sensors in snow to reach close to vapor saturation conditions, in a temperature controlled box. The applied conditions varied between -4°C and -14°C, and between 85% and 100% RH. A HMP110 (Vaisala) sensor was used as reference humidity value. As the humidity error is correlated to the temperature, a linear correction was applied. In our range of temperature, the correction was between 0 and 8%."

Also, having done further analysis on the sensors data, we decided to remove the SHT15 data because of acquisition errors, and to only use the PT100 data for the temperature, and the SHT25 data for the humidity (as the SHT25 temperature sensors are less accurate). Because of the humidity uncertainty (increased by the removal of one set of sensors), we decided to shorten the analysis of the vapor supersaturation in the new version of the manuscript.

The authors state that the initial density is almost constant. Their figs. 5 and 9 clearly show density fluctuations of up to about 30% at a distance of a few millimetres. Such density variations strongly affect thermal gradients and, therefore, snow metamorphism. A detailed interpretation of thermal conductivity and temperature gradients is necessary.

Figure 5 and 9 of the paper show the vertical profile of snow density computed on a 2.1 mm moving windows, for Experiment A and B, respectively. At this resolution, density variations up to 30% can be seen for the Experiment A, mostly at the initial stage as they smooth out with time. Those variations were formed during the sieving process to create the snow layer. Sieving induces vertical variations as well as spatial variations within the snow layer. Those initial density variations at the mm-scale have no major impact on snow metamorphism as no related variation at the mm-scale was found in the specific surface area or the correlation length, which both reflect metamorphism. In the paper, the significant result that is pointed out is the development of coarser grains (higher correlation length, lower specific surface area) in an area of ~ 4 cm height located in the middle of the snow layer. This temporal evolution on a cm-scale area of the snow layer shows no correlation with the density fluctuations, observed at a mm-scale. The effect of mm-scale density fluctuations was thus of second order for the metamorphism described here.

As pointed out by Reviewer 2, we clarified the description of the vertical profile of density to include the mm-scale fluctuations, such as "The overall density remains constant along the vertical, around 220 kg m^{-3}, although significant initial vertical variability can be observed, mainly caused by the sieving process."

The mean covariance length (which should probably read "mean correlation length") is given without a directional index, and no formula or precise reference is given for its calculation. Is the mean covariance length averaged in the horizontal and vertical directions?

Yes, the mean covariance length is the averaged of the covariance length in the x-, y-, andz- direction. We improved the description of the mean covariance length in the new version of the manuscript, such as "The covariance (or correlation) length l_c, which corresponds to the characteristic size of a heterogeneity made of an ice grain and a pore, was calculated along the x-, y- and z- directions of the images, as in the work of Calonne et al. 2014. In this study, we mainly use the average of l_c^x, l_c^y, and l_c^z, referred as the mean covariance length in the following."