## Authors' reply to referee comments RC1

We thank very much Reviewer 1 for the comments that help improving the manuscript. Please find below our point-by-point replies in green color.

General comments

This paper conducted cold chamber experiments for continuous observation of snow metamorphism under the strong temperature gradient approximately 100 K/m and clarified the heterogeneous grain growth. As the authors say, there have been several previous studies in which snow layer was continuously observed in a low-temperature chamber using X-ray CT, but the novelty of this paper lies in the experiment that the vertical structure of the approximately 10 cm snow layer was observed precisely and continuously. By applying a strong temperature gradient to a thick snow layer, the different regimes of crystal growth within a single snow layer were achieved. The authors also mentioned a decrease in the density at the bottom of the snow layer, and the formation of hard depth hoar. These results will provide fundamental data for snow transformation modeling and snow stability prediction.

Specific comments

1. The authors mention that different regimes of crystal growth were observed depending on the temperature range. Figure 11 shows in the height direction for each temperature zone, but the columns and plates are very difficult to see from the 2D image. Photographs of the particles or a 3D surface rendering would be appreciated.

In experiment A, the covariance length in the middle of the snow layer increased faster than in the top and bottom. We hypothesized that this differences in grain growth could be due to the effect of the crystal growth regimes, temperatures in the middle part falling in the basal growth regime whereas temperatures in the top and bottom parts falling in the prismatic growth regime. Hence, the impact of different regimes of crystal growth was identified through differences of growth rate, and of the overall microstructure, but not based on differences in crystal habits, i.e. individual column-like or plate-like crystals. Indeed, as mentioned by the reviewer, the snow structure is really intricated and no isolated columns or plates were observed in the snow layer. This can be seen in the 2D images (Figure 4) and 3D images (Figure 6). This contrasts with the crystals reported in the Nakaya diagram and in Akitaya et al . 1974, which present clear crystal habits. However, such crystals were observed in air or large pore space. We believe that within snow, grain growth is constrained in space by the surrounding grains, which may prevent the growth of fully-developed columns or plates. Yet, it seems that in Arctic snowpack, snow with clear crystal habits can be observed, as presented in Sturm and Johnson, 1991. Dedicated work should be done to further investigated this topic, for example lower snow density, longer and more severe temperature gradient could be reproduced to closer mimic Arctic conditions.

2. Sturm and Johnson (1991) reported that the depth hoar near the bottom of the natural snowpack in Alaska has a C-axis that is oriented almost horizontally in some places and is growing horizontally. (same figure of Fig. 2 of Sturm and Benson (1997)).

In this range of prismatic growth, did the prismatic face of the snow with the C-axis oriented horizontally grow vertically and the horizontal basal growth was not observed?

We agree with the Reviewer that, in the prismatic growth areas of the snow layer (top and bottom) one could expect an enhanced growth of the prismatic faces in the vertical direction, which is the direction of the temperature gradient. In our study, it is however not possible to observe such detailed grain evolution, as we would need to access the grain crystalline orientations as well as in vivo monitoring to track the same grains over time, as the analysis by Granger et al. 2021 with diffraction contrast tomography. Here we can only comment that indeed snow structures grew preferentially in the vertical direction compared to the horizontal one (increase of the anisotropy coefficient), but without being able to distinguish whether this vertical growth was rather occurring on prismatic or basal faces. As mentioned in the previous comment, we did not observed sufficiently representative column or plate crystals from which crystalline orientations could have been guessed, as in Sturm and Johnson 1991.

3. The experiment with large temperature gradients at very low temperatures is similar to that of Kamata and Sato (2007). However, Kamata and Sato's experiment lasted 5.5 days, whereas the authors observed for about a month. The authors would mention what differences they found over a longer period of time, although there is a description of a large change in the initial period.

Besides the experiment duration, others parameters differ between Kamata et al. 2007 and our work. In Kamata et al. 2007, the temperature gradient is much higher (530 versus 100K/m), which led to faster metamorphism. On the other hand, the temperatures imposed by Kamata et al. 2007 are cooler than ours (from -12 to -65°C versus our experiments (from ~ -3 to -17°C), which would tend to inhibit metamorphism. Thus it is not straightforward to compare our studies in terms of final metamorphism stage, taking into account temperature gradient, mean temperature and duration.
In our work, the month-duration of our experiment allowed to obtain a clear signal in the microstructure evolution: the snow layer differentiation for Experiment A and the specific surface area increase resulting from the hard depth hoar formation for Experiment B, as described in result section of the paper. Both features were hardly observable in the first to intermediate stages of the evolution.

4. The differences in temperature ranges appearing in the long vertical samples lead to interesting results. However, since the number of experiments was only two, it is hoped to increase the number of experiments to obtain a data set in future work. Kamata and Sato also have a few experiments, so these experiments will provide valuable data.

The work of Kamata et al. 1999 was included in the introduction to mention the temperature and temperature gradient effect on depth hoar formation. We agree that additional experiments would be needed to further investigate the impact of temperature and crystal growth regime on snow within a snow layer, as mentioned in the conclusion of the paper.

Technical corrections

Line 77

“Those evolution” is “Those evolutions”

Line 306

“can not explained” is “can not explain”

Line 590

“Yosida: “ is “Yosida, Z.”

All the above technical comments were taken into account and modified as suggested in the new version of the manuscript.