We thank the anonymous referee for their valuable and constructive feedback. Their detailed and professional review was very useful and important for improving the manuscript. Here below, we provide a point-by-point response letter addressing the comments. Our responses are in blue and the line numbers (L) refer to the manuscript. The cited references are provided at the end of the letter.
We thank you for your time and effort. Stay safe and take care.
On behalf of all the authors,
Sincerely,

Vilna Tyystjärvi

The manuscript presents an analysis of winter near-surface temperatures along a south-north transect, going from boreal forest to tundra regions in Finland. The manuscript studies the drivers affecting the near-surface temperature in winter using a Structural Equation Modelling framework for the boreal and the tundra regions. Results show that snow cover duration has a strong control on soil temperature, but with opposite effect for mid-winter compared with late-winter. Site with shallow snowpack show stronger spatial variability, while site with flat topography and deep snow show strong decoupling between air temperature and soil temperature.
The manuscript is overall well written and generally show expected results. The findings of the study are not necessarily new; however, the dataset is quite extensive along a south-north gradient, which add some value to the study. The analysis is based on an interesting statistical approach which allows to see the interactions between the different drivers. However, such approach limits the applicability of the findings and in that sense a discussion on the possibility to use the dataset to improve physical modelling of snow and soil temperature could be interesting.

> Thank you for the feedback! We agree that combining this dataset with physical snow modelling would be interesting and is certainly something we have thought to research in the future. While we do not think the findings of this study directly benefit modelling in a concrete way, the possibilities of the dataset should be discussed more thoroughly. We will discuss this in more detail in section 4.

Some aspects of the methodology should also be clarifier. Overall, the manuscript is suitable for The Cryopshere, but proper improvement should be brought to the manuscript.

1. The abstract can be clarified. For example, mentioning “seven study areas across boreal and tundra landscapes”, it seems that the study was made across the northern hemisphere. It is important to clarify the study extent. There should be one or two sentence on the method used to get to the results (statistical approach).- Also, the results based on snow cover duration and the SEM is not quite clear in the abstract.

Thank you for the suggestions on improving the abstract. We will clarify that the study domain covers Finland. We will add that the results are based on empirical methods, explaining shortly the approach to estimating snow cover duration as well as the statistical model that we used. We will also clarify in the abstract that the results concerning snow cover and its impact on near-surface temperatures are based on the variation of snow cover duration. We will also add what the main findings from the SEMs are.

2. Line 38: “slow down snow melt during spring through energy balance controls”. It is more complex than that. There are melting related to tree radiation around the trunk. It is mentioned in the discussion. Need to be clarify here.

This is a good point. The effect of canopy on below-canopy microclimates and thus snow melt is indeed more complex and depends on, for example, canopy structure and tree species composition and local topography (Ellis et al. 2011) as well as basal area (e.g. Musselman et al. 2017). We will expand this part of the introduction.

3. Figure 1. There is a need to clarify what represent c and d. Is it a histogram of all study sites for each study area?

The panels c and d show density curves of near-surface air temperatures (c) and snow cover duration (d) in all study sites within each study area. We will clarify this in the figure caption.

4. It is important in the text to well distinguish between “study area” and “study site”. Sometimes, it can get confusion. Maybe using clear acronym for each could help?

Thank you for pointing this out. We will go through the text carefully to make sure that it is always clear when we are discussing about study areas and when about study sites and what the discussed level of variation is in each sentence. However, we do not think that an acronym for each would make the text easier to understand but rather complicate it further.

5. Line 91: There is a need to clarify what “-6” means. Is it 6 centimeters under the surface. So it means that the 2 cm is above the surface? So it means that the means surface is 2 cm above the ground? Needs to be clarify. How the sensors were kept above the surface?

The sensors measure temperatures 6 cm below the ground, as well as 2 cm and 15 cm above the ground surface. When discussing near-surface temperatures, we mean near-surface air temperatures. We will clarify this focus on air rather than soil temperatures in the beginning of the manuscript and explain in more detail in section 2.2 what the measured temperatures are. The sensor is a stick-like logger which is carefully pushed to the soil to the correct depth and stays in place by itself (Wild et al. 2019).

6. Snow Cover duration: I have some doubt about the snow cover duration calculation. Why using the 15 cm? Even if the 15 cm is not cover by snow, it doesn’t mean the 2 cm is not cover by snow? But the problem with using 2 cm to get the snow cover duration is that you would use the same measurements to get the snow cover duration and the impact of snow on near surface temperature. This point needs to be clarified/discussed.

This is a good point. It is true that there is some insulating effect from a thin snowpack as well. However, as the insulating capacity of a snow pack increases with increasing depth (e.g. Zhang 2005) and shallow snowpacks have been shown to poorly explain the temperature decoupling between temperatures below the snowpack and above it (Grundstein 2005), we decided to focus on periods with over 15 cm of snow as we expected that to better describe the buffering effect of a snowpack. However, we recognize that this should be more explicitly explained in the manuscript and will clarify this in section 2.4. We will further consider the limitations of this approach in section 4.3.

7. In addition it is not clear if the snow cover duration was calculated for each “study site” or each “study area”. Figure A1 is confusion because it shows all the near surface temperature at 2 cm (? need to be clarify) and the snow cover duration. However, that would be interesting to show the 15 cm temperature and air temperature to see how the snow cover duration was calculated.

The snow cover duration was calculated for each study site. We will clarify that in section 2.2. In Figure A1, the bottom (top) line of the dark grey ribbon shows the daily minimum (maximum) near-surface temperatures measured at 15 cm height in the sites mentioned. We appreciate that this should be phrased more clearly in the caption. Air temperature was not used in the algorithm, so we do not think that adding it to the figure would help in understanding how the algorithm functions.

8. Line 147-150: These sentences are confusing. It seems that the calculations were done for each “study area”. However, all the data is available to make the calculation at each “study sites”. From these sentences, I understand that the snow cover duration is calculated for a study area, when you can calculate it at each study site. It would be very important to clarify this point and clarify how many “N” are used in the SEM.

We understand that the sentence is currently confusingly written. The temperature variables as well as the snow cover duration were indeed calculated for each study site separately even though this was not explicitly mentioned in the text. In the calculation of the temperature variables, the timing of the “mid-winter” and “late winter” was defined for each study area collectively to keep this aspect of variation similar within the study areas. We will restructure these sentences to be more accurate and easier to understand.

9. It also seems that the total snow cover duration is used as a variables in the SEM to explain the near-surface temperature in mid-winter. It seems inadequate to use a full winter snow cover duration as a variable to explain near-surface temperature in the

middle of the winter? Maybe looking at the beginning of the snow cover would make more sense?

This is a good question and we understand that this point will need further explanation. As can be seen for example in figures 3 and A2, the beginning of the snow cover season is more uniform within the study areas and does not necessarily describe the accumulation patterns within the landscape as well as the total snow cover duration or snow melting date. Our reasoning for using the total snow cover duration is that this is likely to more accurately reflect where snow does and does not accumulate in a landscape, and therefore better represents the buffering effect of snow, as the more snow accumulates in a certain place, the longer it will take for it to melt as well. As can be seen in figure 5, the total snow cover duration does indeed correlate strongly with mid-winter near-surface air temperatures. However, we understand that this effect is not always obvious and regarding the melting, the whole picture is more complex, as noted in a previous comment concerning the effect of forest structure. We will add further explanation in section 2.6 concerning our choice of variables. We will also discuss the limitations of this approach further in section 4.2. We will also repeat the mid-winter SEMs using the beginning date of the snow cover season and add these in the supplement to provide further information on the effect of the timing of the snow cover season on near-surface temperatures.

10. Would be important to mentioned if the study area are in permafrost regions. It will have a impact on the thermal regime of the soil and thus on the near-surface temperature.

This is a good point as the most northern areas of the study domain are close to permafrost regions. There is no permafrost within the actual study areas and we will clarify this in section 2.1.

11. Would be useful to give a more representative acronym for the “beta”.

We will change the acronym to slope which should also describe the variable appropriately.

12. line 207: “Snow cover duration had a strong positive effect (0.73) in mid-winter”. It is quite surprising to get such a strong relation when the end of snow season should not have any impact on the mid-winter soil temperature?

As we explained above, while it is true that the end of the snow cover season does not directly affect mid-winter temperatures, it does reflect snow accumulation patterns which do strongly control mid-winter conditions. As mentioned in a previous comment, we will further clarify this in section 2.6.

13. Figure 6: Should clarify what is on Y axis. Also “linear regression model calculated from a two-week moving window”, add “(beta)”

The y-axis in all the panels shows beta. We will clarify this and modify the caption as suggested.

14. In the discussion, it will be important to mention the soil thermal regime. Your measurement are above the ground (2 cm) if I understood well. However, it is well known that a wet soil will stay at zero curtain longer because of the latent heat. Permafrost can also alter the soil thermal regime. Even if the measurement are not done in the soil, the author have to recognize the potential strong impact of soil on the results, which are not considered in the study.

This is an excellent point. While considering soil-related processes governing near-surface temperatures was outside the scope of this study, the soil thermal regime and its variation is important and we look forward to addressing it in more detail in a future study. Here we will, as suggested, add discussion on the impact of soil properties, including soil moisture, on near-surface air temperatures in section 4.2.

15. As mentioned earlier, the results are interesting, but not quite new. Ideally, the study would have been conducted using snow physical modelling. But I understand that it is not the scope of the work. However, should be important to relate the results to possible improvement in soil temperature modeling.

While the approach of this manuscript was empirical, we agree that it would be interesting to combine our dataset with a physical snow model. In our opinion, the most relevant finding of this manuscript, concerning snow and winter microclimate modelling, is the considerable magnitude of landscape-level variation and the need to take this variation into account in order to accurately

simulate snow cover and its impact on winter microclimates. More concrete improvements of snow modelling would, in our opinion, require a different approach than the one in this manuscript but we look forward to addressing this in future studies.

16. Figure A2: not clear what “predicted” mean in that context?

Predicted here refers to the prediction made by the snow cover algorithm. We will clarify this in the caption.

References:

Grundstein, A., Todhunter, P., and Mote, T. (2005), Snowpack control over the thermal offset of air and soil temperatures in eastern North Dakota, *Geophys. Res. Lett.*, 32, L08503, doi.org/10.1029/2005GL022532.

Musselman, K. N., & Pomeroy, J. W. (2017). Estimation of needleleaf canopy and trunk temperatures and longwave contribution to melting snow. Journal of Hydrometeorology, 18(2), 555-572.

Wild, J., Kopeckỳ, M., Macek, M., Šanda, M., Jankovec, J., and Haase, T. (2019). Climate at ecologically relevant scales: A new temperature and soil moisture logger for long-term microclimate measurement, Agricultural and Forest Meteorology, 268, 40–47, https://doi.org/10.1016/j.agrformet.2018.12.018.