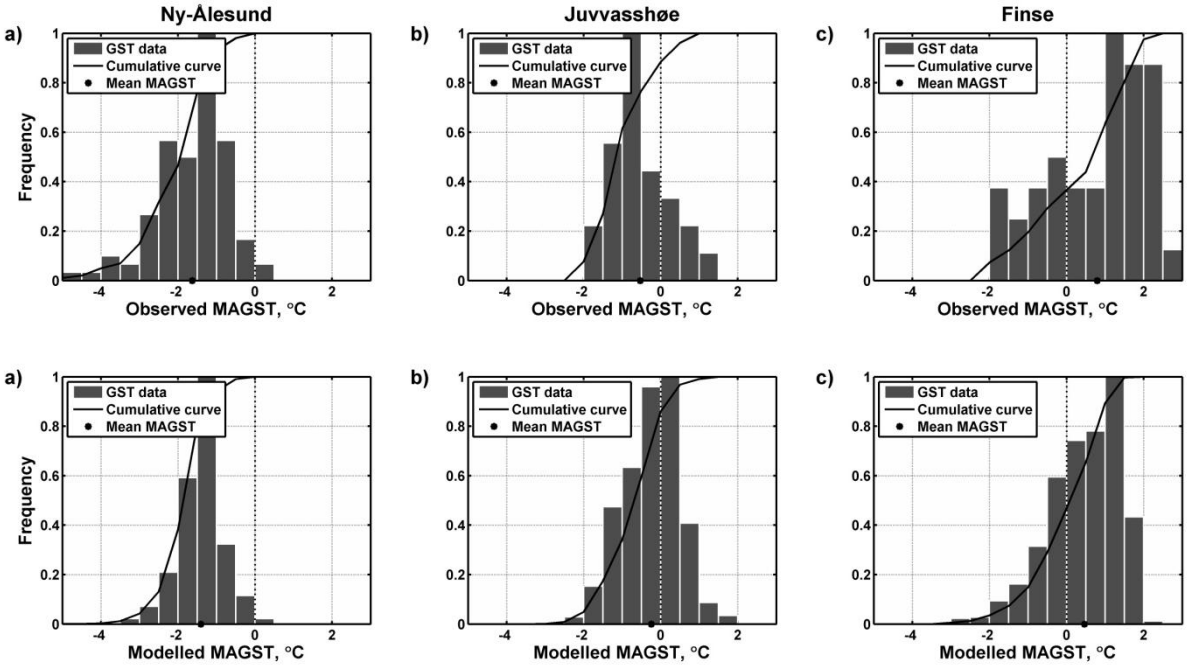
Reply to Referee 1#'s comments regarding the article *"A statistical approach to represent small-scale variability of permafrost temperatures due to snow cover"*.

Referee comments are in bold, our answers are without formatting, and *changes to the initial manuscript are in Italics*. Common points raised by all reviewers were:

A) The n-factor relations are not fully independent from the dataset used for the calibration.

We have changed the model approach with a nF-factor relation based on an independent dataset of 15 stations distributed in 3 different mountain areas in southern Norway. The dataset contains observations of air and ground surface temperatures as well as maximum height of snow over the period 2009-2012. This is the same dataset that makes the basis of the nF-factor relation used in Gisnås et al (2013), except one more year that is now included. The nF is now given as: nF = -0.187 * ln(HS) + 0.399 where HS is maximum height of snow in meters. We have cut the snow-dependent relation of nT-factors, and use a constant nT value of 1, following the value for the surface class "barren ground" in Gisnås et al. (2013).

The new distributions are as follows (measured in first row, modelled in second row):



Changes:

Page 517, line 20: Changed into:

*where nF = -0.187*ln(HS) + 0.399, and nT has a constant value of 1. This relation is based on independent observations of air and ground surface temperatures as well as snow height at 15 stations in southern Norway over the period 2009-2012, published in Gisnås et al. (2013).*

Table 2 is cut and changed into a result table (see comment at Pg 518 from referee #1).

Page 519, line 20 – 27 + page 520, line 6 – 10: Modelling results are updated.

Fig. 5 is updated.

B) Why are other surface characteristics, such as aspect, slope, solar radiation, sediment and vegetation type not investigated to show that snow is a dominating factor?

Surface characteristics including sediment type, vegetation cover, aspect, slope and wetness have been recorded for 107 logger locations, in addition to maximum snow height and days of snow cover. From regression analysis of all factors it was clear that maximum snow height to a large degree explains the small scale variation at our sites. This supported by Fig.3 where the largest spatial variation in mean monthly GST clearly is found during mid winter (Dec – March), and is also strongly indicated by the fact that including height of snow in a simple model strongly improves the modelling result. The importance of snow on ground temperatures in similar areas have been highlighted in several previous publications (Westermann et al., 2013; Gisnås et al., 2013; Farbrot et al., 2011; Isaksen et al., 2002; Isaksen et al., 2011). We agree that a detailed statistical study of these data would be interesting; however, this would extend the scope of this paper and lengthen the manuscript significantly. The focus of this paper is that the distribution of ground temperatures to a large degree can be reproduced using a simple approach only including one parameter. We have therefore chosen not to include the full statistics of all surface characteristics for this manuscript, but could of course include it after an editor decision.

Below we present a point-by-point response to all individual referee comments:

Pg 510, line 19-20 – Snow cover can also affect the freeze-back of active layer in the fall and winter. At the considered study sites, we consider this effect of minor importance for the spatial variability since the snow cover variability are comparably small during summer and early winter (see fig. 3). However, it may be an important factor under different environmental conditions.

Pg 511, line 1-3 – Suggested revision: "The strong redistribution of snow by wind results in accumulation of snow in deep hollows, while large open areas are bare blown." This is changed.

Pg 511, line 23 – Suggested revision: replace "implemented" with "established". This is changed.

Pg 511-514 – Study site description: Information on surficial materials is not provided for all study areas and it would be good to include this. Information on moisture/ground ice conditions would also be useful. Sparse vegetation is mentioned for the Juvvasshoe site but there is no comment on the vegetation for the other sites – is it also sparse?

The following is included for clarification:

Page 214, line 5: *Finse is located in the high Alpine zone, with sparse vegetation, consisting mainly of mosses and lichens. The bedrock is only partly covered by a thin sediment cover or blocky material.*

Page 212, line 23: *The surface cover in Bayelva area alters between mud boils and sparse vegetation consisting of low vascular plants, mosses and lichens. The soil texture is silty to clayish in a gravely matrix, and is in general low in organic content (Boike, 2008).*

Pg 512, line 7 – Is there a more recent climate normal for the study area such as 1971-2000 or 1981-2010? This would be more representative of current conditions. We considered the normal period 1961-1990 as the most important here, but included also the 1981-2010 period.

Pg 513, line 9 – Suggested revision: "…and indicates permafrost extends below a depth of 300 m" or "… and indicates permafrost is more than 300 m thick" The following change is done: *"permafrost extends below a depth of 300 m"*

Pg 513, line 22-23 – It may be better to say that snow heights of 1.5 to 2.0 m are possible. (Was average density utilized to determine the snow cover thickness? – you could perhaps say something about how you arrived at these values.) These values are from the gridded snow dataset produced by the Norwegian Meteorological Office and the Norwegian Water and Energy Directorate. Snow water equivalent and snow height is modelled from precipitation and temperature data, using a model also accounting for density in the snow pack. We changed into: "*…calculated average snow height (without accounting for snow drift) was 1.5 - 2.0 meters (seNorge.no, 2013; Tveito et al., 2000; Mohr, 2008; Saloranta, 2012) "*

Pg 514, line 7 – Revise: "…estimated to be 1550 m a.s.l." Done.

Pg 515, line 1-2 – The loggers were utilized to measure surface temperature throughout a complete year (or almost a complete year) but this sentence implies that temperatures were only measured during the winter season. Perhaps you could say that measurements were made over the hydrologic year that includes the winter season 2012-13. The following is included: "*one hydrological year including the"*

Pg 515, line 12 – Was a random number generator utilized to select sites and achieve the random distribution. The random number generator in MATLAB was used to select sites in Ny-Ålesund. The following sentence is included: "*…,with coordinates generated by a random number generator".*

Pg 516, line 3-4 – Are there any errors introduced due to packing of snow as the snowmobile travels over the surface? A small offset might be introduced by the snow mobile, but since the radar surveys were done late in winter at snow maximum with a relatively to very compact snow pack, this offset was minor.

Pg 517, line 11 – Define MAGST (mean annual ground surface temperature). This is included as suggested.

Pg 517, line 10-15 – Since you do not determine or discuss TTOP in this paper it may be misleading to refer to the TTOP approach here. You could just say that n-factors are used as transfer functions between air and ground surface temperatures and (as you correctly point out) represent the surface offset. This is corrected as suggested.

Pg 517, line 25-26 – Perhaps this statement should be incorporated into the discussion section. In this paper you do not really estimate TTOP but rather are focussing on improvements in characterization of GST which can be used with your model to determine TTOP and characterize permafrost distribution etc. In the discussion you could say more about how the improved estimates of GST can be used as model inputs to improve TTOP estimates etc. The sentence is moved to page 520, line 9.

Pg 518, Results section – You could possibly summarize your results in a table which would include mean and standard deviation for MAGST, snow depth, duration etc.

As suggested we have included a table of the results, together with the modeling results. The table will come after the modeling results chapter (4.3).

Table 2: Variation in observed mean annual ground surface temperatures (MAGST) for 2012-2013 at the study sites, given as mean, minimum, maximum and standard deviation of MAGST from all the loggers at each site. The percentage of loggers with MAGST below 0°C is given under "% < 0°C", and the skewness of the distributions of MAGST is given as a number between -1 and 1.

MAGST	*Mean*	*Minimum*	*Maximum*	*Standard Deviation*	*% < 0°C*	*Skewness*
Observed MAGST						
Finse	0.79	-1.84	2.65	1.26	30	-0.59
Juvvasshøe	- 0.53	-1.75	1.05	0.75	77	0.58
Ny-Ålesund	-1.63	-4.64	0.46	0.93	98	-0.74
Modelled MAGST						
Finse	0.46	-2.69	2.10	0.92	29	-0.76
Juvvasshøe	-0.25	-2.88	1.68	0.73	60	-0.21
Ny-Ålesund	-1.40	-4.33	0.60	0.58	99	-0.41

Pg 518, line 21-22 – Revision suggested: "…with ground surface temperatures close to 0°C at many of the measurement sites." Done.

Pg 519, line 9-12 – Although snow cover is an important factor influencing nF, the amount of latent heat released by the active layer during freezing in fall/winter (which will depend on active layer thickness as well as substrate moisture conditions) can determine how important snow is as an insulator – see Smith and Riseborough (1998); Throop et al. (2012). Snow cover therefore has a greater effect on nF where permafrost is warmer and also where soil moisture contents are greater. It might be interesting to see if there is any difference in nF between wet and dry sites that may have similar snow cover. Variable moisture conditions could be responsible for some of the variability in nF (and GST).

Soil moisture is related to nF-factors, but in our study we found that small-scale variability at the scale we operate has a higher correlation to snow cover than to soil moisture. But we agree that the total effect of the snow as an insulator in general will depend on the amount of soil moisture, and it would certainly be interesting to do this analysis on the dataset in a separate study. However, to focus the paper and keep it short these analyses are not included here. See further comment B) in the introduction. We have included the following sentence:

The effect of the snow as an insulator is also related to the amount of heat released by the active layer during freezing (Riseborough, 1998; Troop et al., 2012), but this effect has not been included here.

Pg 519, line 19- Pg 520, line 8. Some clarifications are probably needed in this section. Snow depth determined from the GPR surveys are utilized to determine MAGST using CryoGrid. What is the resolution of the output and over how large an area is MAGST determined to produce the distribution shown in Fig. 5? It is not clear whether a point to point comparison between modelled and measured MAGST is presented or rather the

modelled values (and distributions shown in Fig. 5) are for the entire area for which the snow cover distribution has been determined. The concern I have is that the same data are being used for model validation as those used to determine the relationships between snow depth and n-factors.

See point A) in the introduction

Pg 521, line 1-12 – You could probably say it is both the mean and variability that is important (i.e. more variability in GST when the snow cover varies around a mean value that is less than 1m than when it varies around a mean value that is greater).

Corrected sentence at line 4:

…,which is reflected in relatively larger variability in GST when the snow cover varies around a mean value less than 1 m than above.

Pg 523, line 2-6 – You might mention that this is important for determining local scale impacts on drainage and ecosystems resulting from changing permafrost conditions. It might also be worth mentioning that information at this scale is also required for infrastructure planning and design. We agree this is an important perspective, and we have included the following sentence in line 6: *This is also important for determining local scale impacts on drainage and ecosystems resulting from changing permafrost conditions, as well as for lowering the costs related to infrastructure planning and design.*

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