Response to Reviewer #1:

We would like to thank Reviewer #1 for these valuable comments. Below are the responses to all Reviewer #1's comments and how we address them in the revised manuscript. **Texts in red** are the reviewer's comments; **those in black** are the authors' explanations to the reviewer's comments; and ***those in blue*** are the revised texts in the revised manuscript.

RC1: Convective Heat Transfer of the Spring Meltwater Accelerates Active Layer Phase Change in Tibetan Permafrost Areas
By Zhao et al.,
In this study, the authors applied the SHAW model to investigate temperature dynamics at the Tanggula site at the Eastern Qinghai-Tibetan Plateau. The modeling experiment includes the cases: 1. control (fully coupled diffusion convection), 2. NoSurf (no convective heat flux between surface and subsurface, but preserves the convective flux in the subsurface as a results of water movement in soil pores), 3. NoConv (no convective heat flux from surface to subsurface as well as no flux due to water movement in the subsurface). If I understand correctly, in case 2, the second left term in eqn. 2 remains for the subsurface formulation and is completely removed from the eqn. 2 for case 3.
Overall, the study is interesting and well presented.
Authors: Thank you for your positive comment.

RC1: I suggest including a discussion on a similar mathematical formulation described by Painter et al., (2016). How is the current mathematical formulation different from Painter et al. What are pros and cons of each formulation?
Authors: Thank you very much for providing this information. We have not previously mention Painter's work because it is related to a 3-D model that is not applicable to the study area (Qinghai-Tibet Plateau, QTP) due to the very high data requirements. We used a 1-D model instead to perform the permafrost simulation. We have read his paper and other related papers during this revision period, and found them to be very helpful for our future work.
In this revision, we cited Painter's study and some similar studies on permafrost process modeling, in which CHT is incorporated into the energy balance, in the Introduction section:
"A number of traditional schemes for soil heat transport have been further developed with enhanced vapor/liquid CHT processes and have been shown to be effective in cold regions (He et al., 2018; Kurylyk et al., 2014; Wang and Yang, 2018).Furthermore, researchers have recently begun to formulate soil heat and water transport processes within a three-dimensional framework to provide a more reasonable physical expression for vertical and horizontal heat and mass transport (Orgogozo et al., 2019; Painter et al., 2016)."
Further, we have discussed the advantages of a 3-D LSM over the 1-D one in the Discussion section 4.3. By coupling both horizontal and vertical thermal and hydrological processes at the surface/subsurface, those 3-D models make them advantageous over 1-D model like the SHAW model in representing the surface/subsurface water migrations and the thermal consequences on permafrost.

"In addition, Kurylyk et al. (2016) mentioned the potential thermal impacts caused by lateral discharges in permafrost regions, while relatively small. Unfortunately, it is not investigated in this study because the one-dimensional SHAW model ignores lateral water migration from the perimeter into the soil column due to soil anisotropy, which may lead to some uncertainty in simulating water flow within the active layer. Recently, 3-D LSMs have emerged as found in the recent literature (Endrizzi et al., 2014; Painter et al., 2016; Rogger et al., 2017). Those models couple both horizontal and vertical thermal and hydrological processes at the surface/subsurface and own obvious advantages over 1-D models in terms of the physical basis for studying surface/subsurface water migrations and the thermal consequences on permafrost. Although current observations on the QTP cannot meet high data and parameter demands of 3-D models for, this provides another direction for CHT studies on the QTP. "

RC1: Is q_l a Darcy flow or water head potential in the current formulation? My understanding was that the current model considers both saturated and unsaturated soil conditions. It would be nice to include the discussion on the compute time difference between saturated and unsaturated cases.

Authors: q_l is determined by the hydraulic conductivity and water head potential difference between two soil layers. We have provided Eqs. (3-6) about liquid water migration in Section 2.1 of the revised manuscript to avoid possible confusion. If I understand correctly, the SHAW model does not separately treat saturated and unsaturated soil conditions. Rather, it considers the saturated flow as a special case of unsaturated condition with saturated hydraulic conductivity and water potential.

"$$K = K_s \left(\frac{\Psi_e}{\Psi}\right)^{\left(2+\frac{3}{b}\right)} \quad (3)$$

where K_s is the saturated hydraulic conductivity (cm ·h-1), b is an empirical parameter representing pore size distribution, and Ψ_e is the air entry potential (m) for the saturated soil layer. ψ is computed as a function of soil moisture:

$$\Psi = \Psi_e \left(\frac{\theta_l}{\theta_s}\right)^{-b} \quad (4)$$

where θ_l and θ_s are the liquid water content (m3 ·m-3) and soil porosity (m3 ·m-3), respectively. Then, the vertical water flux q_l could be calculated by the water potential difference and the relative conductivity $K_{n,n+1}$ between layer n and n+1:

$$K_{n,n+1} = (K_n \cdot K_{n+1})^{\frac{1}{2}} \quad (5)$$

$$q_l = \frac{K_{n,n+1}}{z_{n+1} - z_n}(\Psi_n - \Psi_{n+1} + z_{n+1} - z_n) \quad (6)$$"

RC1: What is the equation for the vertical water flux? It is not clear how one would define subsurface water transport without addressing the soil permeability?

Authors: The equations related to soil ice content and soil permeability due to ice have been added as Eqs.(7-11) in the revised manuscript:

“If the soil temperature is below 0 ° C and ice is present, the total soil water potential is estimated using a modified Clausius-Clapeyron equation:

$$\emptyset = \Psi + \pi = \frac{L_f}{g}\left(\frac{T}{T_K}\right) \quad (7)$$

where $\emptyset$ *is the total soil water potential,* Ψ *is the matric potential from Eq. 4,* π *is the osmotic potential (m) with respect to solutes in the soil,* g *is the acceleration due to gravity (m ·s-2),* L_f *is the latent heat consumption during phase change (kJ ·kg-1), and* T_K *is the freezing point (°C). Thus, the unfrozen water content and ice content can be solved by combining Eq. 4 and Eq. 7:*

$$\theta_l = \theta_s\left(\left(\frac{L_f T}{g T_k} - \pi\right)/\Psi_e\right)^{-\frac{1}{b}} \quad (8)$$

$$\theta_i = (\theta_w - \theta_l)\frac{\rho_i}{\rho_l} \quad (9)$$

where θ_w *is the total water equivalent in the soil layer. When ice content is present, hydraulic conductivity is inhibited:*

$$K_i = \begin{cases} 0, & p - \theta_i < 0.13 \\ f \cdot K, & p - \theta_i \geq 0.13 \end{cases} \quad (10)$$

where p *is the available porosity, and* f *is a fraction for linearly reducing the soil hydraulic conductivity:*

$$f = \frac{p - \theta_i - 0.13}{p - 0.13} \quad (11)”$$

According to these equations, soil permeability in SHAW model is jointly limited by ice content, soil texture and hydraulic characteristics such as porosity and hydraulic conductivity. When the soil freezes and the available porosity is less than 0.13, the soil permeability is set to 0, and when the available porosity is more than 0.13, vertical flux is allowed but limited.

RC1: I suggest including the permeability paragraph in the Discussion section. During snowmelt, the surface is typically frozen. That said, most if not all of the snowmelt water should runoff the surface. Not clear why it would percolate into the subsurface? Westermann et al., has a publication on the effect of water percolation in the snow layer and its impact on surface temperatures, worse to mention as well.

Authors: Thanks for this very important comment. According to our experiments, there can be two effects of snowmelt relating to convection on soil temperature. One is related to infiltration of snowmelt water into the soil, and the other is related to an indirect effect due to the change in the surface temperature gradient, which then alters the temperatures of the underlying soil. The latter effect can occur even when the surface is frozen and no liquid infiltrates into the soil.

The first effect is apparently observed during the spring melting periods, when the snow is melting and the soil may be not yet be completely thawed. As shown in Eq.10 and 11 in the revised manuscript, the SHAW model allows liquid water migrates between soil layer when ice content is low. Therefore, in spring, even if the soil layer is not yet completely thawed, spring snowmelt can slowly infiltrate and carry convective heat to the soil layers.

The second effect is the one you are concerned with. We observed such an effect in the January 2010, when the soil layer was completely frozen and impermeable, but some small snowmelt events affected the temperature of the shallow soil layers. On those occasions, we found that convective heat transfer (CHT) does not directly affect the soil thermal regime by infiltrating the liquid flow, but indirectly affect that soil layers by altering the thermal gradient at the surface. In this case, although the snowmelt stopped at the ground surface, it altered the temperature at 0.0 m depth and affected the thermal gradient at shallow depths. Then these temperature deviations spread to the lower depths through the changed thermal gradient. Although this type of heat transfer is accomplished through heat conduction, it is still essentially an indirect convection-induced heat transport. In our experiments, we disabled the CHT and retained water flow and heat conduction in the modified models. Therefore, warmer snowmelt from the snow surface moves downward to the ground surface by the original model than by the modified models. Our experiments can precisely produce this indirect effect associated with snowmelt.

Accordingly, we have added a new section, *"Section 4.2 Snowmelt influence on convective heat transfer"*, to discuss the snowmelt-related CHT issues. We would like to show the section here for your reference:

"Snowmelt is a main component of spring infiltration that causes CHT from the ground surface and warms the underlying soil layers, as evidenced by both our study and the observation-based studies mentioned above. Normally, as air temperature warms, snowmelt is accompanied by thawing of the soil, allowing meltwater to freely infiltrate into the soil. This is the main form of snowmelt-induced CHT. However, as shown in our contrasting experiments, the soil temperature of the Control scenario differs from that of the NoSurf and NoConv scenarios even during the periods when no vertical water flux occurs in these layers. This suggests that snowmelt could also have an indirect influence on the soil without explicit infiltration. For example, some snowmelt events took place in January 2010 (Figure 3), possibly due to a transient increase in air temperature or shortwave radiation, resulting in temperature differences between Control and NoSurf/NoConv at shallow depths (Figure 4). However, snowmelt could not infiltrate because the ground was still in an impermeable, frozen state at this time. We assume that in this case the temperature at the ground surface was affected by the convective heat carried with snowmelt, although snowmelt can only move downward through the snowpack and reach the ground surface before it drains laterally, which then affects the thermal gradient at shallow depths. Thus, the altered temperature at the ground surface was spread to the lower layers by the changed thermal gradient. Not coincidentally, we also measured some CHT-induced soil temperature changes at intermediate depths, but at the same time no corresponding convective fluxes were observed, which we believe is also part of the indirect convective heat influence exerted from other depths to this depth by conduction. Although this type of heat transfer is accomplished through heat conduction, it is still essentially an indirect convection-induced heat transport."

We also cited two related studies by Westermann (Magnin et al., 2017; Zweigel et al., 2021) to discuss water redistribution within snow and its impacts on ground temperature at Section 4.2：

"Moreover, percolation of liquid water within snow leads to a complex spatial redistribution of snow depths and densities, which strongly regulates the ground temperature and the active layer thickness in snowpack areas (Magnin et al., 2017). Zweigel et al. (2021) have reported that redistribution of snow, taking into accounts snow water percolation, increased ground surface temperature 1-2 °C, demonstrating another aspect of the indirect impacts of snow water migration on the permafrost thermal regime."

References:

Magnin, F., Westermann, S., Pogliotti, P., Ravanel, L., Deline, P., Malet, E.: Snow Control On Active Layer Thickness in Steep Alpine Rock Walls (Aiguille Du Midi, 3842Ma.S.L., Mont Blanc Massif), Catena, 149, 648-662, https://doi.org/10.1016/j.catena.2016.06.006, 2017.

Zweigel, R. B., Westermann, S., Nitzbon, J., Langer, M., Boike, J., Etzelmüller, B., Vikhamar Schuler, T.: Simulating Snow Redistribution and its Effect On Ground Surface Temperature at a High‐Arctic Site On Svalbard, Journal of Geophysical Research: Earth Surface, 126, https://doi.org/10.1029/2020JF005673, 2021.

RC1: I found Figure 3 not necessarily helpful for understanding the effect of convective heat flow. Does it mean that convective flux adds to the 5C difference in soil temperatures over a short period of time?

Authors: I apologize for not well explaining the importance of Figure 3 in the initial manuscript (now Figure 4 in the revised manuscript because we added new Figure 1 showing the time series of air temperature and precipitation during the study period). Figure 4 is an overall demonstration of the impacts of CHT, presenting not only the soil temperature deviations due to CHT, but also the characteristics of its occurrences in time and at depths. As shown in Figure 4, it is clear that CHT usually works during the spring when snow cover and soil ice begin thawing, and the deeper soil layers are later affected by CHT than the shallow layers. Moreover, Figure 4 also shows that the intensity and frequency of CHT in shallow layers are significantly higher than in intermediate and deep layers. The large difference between shallow, intermediate and deep depths indicates the need for further analysis at different depths respectively. By considering the above reasons, we believe Figure 4 is important to understand the role of CHT in affecting permafrost thermal regime. We have strengthened the importance of Figure 4 at Section 3.2:

"The differences in the soil temperature profiles between the Control and the two other scenarios, i.e., partial (NoSurf) or full (NoConv) exclusion of CHT in the model, are presented in Figure 4b and Figure 4c, respectively, which depict the distribution patterns of CHT occurrence in time and depth, and the intensity of soil temperature variations due to CHT."

We also improved the legend of Figure 4b and c in order to more clearly express the temperature deviation ranges.

RC1: Can the changes that are shown in Figs 3 and 4 be verified against observations or in lab measurements? L353 concludes that convective flux could contribute to up to 10C temperature change during snowmelt. This is massive warming or cooling, which I am having a hard to believe. Short-term 10C warming/cooling should lead to substantial changes in subsurface thermal state over time. Are there any pieces of evidence of the accelerated ground warming in the region?

Authors: Many thanks for your suggestions. Some existing studies have reported such soil warming events due to snowmelt or precipitation. We have added them as cross-validation evidence in the Discussion section 4.1:

"Previous studies have also observed some CHT effects due to the anomalous fluctuations in soil temperature during the periods when snowmelt or rainfall infiltrates into the soil. Kane et al. (2001) and Hinkel et al. (1996) reported the step-like increase in near surface temperature by 2 °C to 4°C and the pronounced disruption of thermal gradients during the periods when snowmelt infiltrates. The increase in soil temperature (Iijima et al., 2010; Mekonnen et al., 2021) and frost front depth (Douglas et al., 2020; Guan et al., 2010) was also observed following heavy rainfall events, indicating that precipitation is another important source of CHT in addition to snowmelt. Kane et al. (2001) estimated that the CHT during heavy precipitation is twice as high as conductive heat. Hinkel et al (2001) measured 0.5 °C and 1.3 °C positive changes in soil temperature in response to infiltration from snowmelt and rainfall, respectively."

According to these observation based studies, CHT due to snowmelt and precipitation usually alters the soil temperature at a range of 0 to 4 °C in several hours, and promotes the thawing of active layer. Although the maximum temperature deviations due to the CHT could reach 10 °C in our study, most of the deviations were limited to less than 5 °C, which is consistent with the observations. In addition, as already stated in the Introduction, although these observed soil temperature warming are mainly driven by CHT, they are still produced by joint effects including heat conduction, advection and convection, and phase change. It is still hard to isolate the sole impacts of CHT from the totality of soil heat regime by observations. Thus, our modelling study provides a good explanation for the mechanism behind these observations, how those warming events at certain depths during spring thaws and rainfall events could occur due to CHT processes alone.

We have strengthened the comparison between previous observations and our results by adding some related discussion in the Discussion section 4.1:

"Although the maximum temperature perturbation due to the CHT process could occasionally reach 10 °C in our study, most of the temperature perturbations were limited to less than 5 °C, which is consistent with the observed phenomenon. Although these observed warming events are mainly driven by liquid convection, they are still a combined product of multiple heat transfer processes, including conduction and vapor flow. On the other hand, our modelling study provides a good explanation for the mechanism behind these observations, how those warming events at certain depths during spring thaws and rainfall events could occur due to CHT processes alone."

RC1: I suggest quantitively estimate the impact of these short-term warming/cooling pulses on mean annual ground temperatures. Are these pulses significant, and on what temporal scale? For example, on the yearly scale, those pulses could be less important than on a monthly scale and so on....

Authors: Thank you very much for this important comment. As per your suggestion, we singled out each CHT events, which is defined as a soil temperature deviation of more than 0.1 °C between Control and NoSurf/NoConv at a time step, and quantify their effects. A temperature deviation of 0.1 °C or less is insignificant and might be caused by model iteration bias rather than CHT.

Despite CHT are relatively slight on the annual scale, we found it could significantly affect soil temperature at the time in which CHT is happened. The total amounts of heating and cooling CHT events and the mean temperature deviations per each CHT event were analyzed for measuring the frequency and magnitude of CHT effects on soil temperature.

We revised the method description as presented in Section 2.2:

"We defined a CHT event as a ground temperature deviation of more than 0.1 °C between NoSurf/NoConv and Control at one model time step. A deviation of 0.1 °C or less is trivial and could be due to model iteration bias rather than CHT. According to their effect, there are cooling CHT events and heating CHT events. The total numbers of cooling and heating CHT events and mean temperature deviations were analysed to examine the frequency and magnitude of CHT effects on ground temperature:

$$\overline{\Delta T} = \frac{\sum_{i=1}^{m} \Delta T}{m} \quad (12)$$

where, $\overline{\Delta T}$ *is the mean temperature deviation of all heating or cooling CHT events,* ΔT *is the temperature deviation caused by an CHT event, and m indicates the count of heating or cooling CHT events."*

Our results were presented in a newly added Table 2:

Table 2 The numbers of heating and cooling CHT events and the mean temperature deviations caused by CHT of 0.05 m, 1.05 m and 2.45 m depths. The deviations of 0.1 °C or less were excluded for statistics.

	Control vs. NoSurf			Control vs. NoConv		
	0.05 m	1.05 m	2.45 m	0.05 m	1.05 m	2.45 m
Number of heating events	2436	1850	602	3109	2984	456
Average increase (°C)	0.86	0.43	0.211	0.972	0.412	0.229
Number of cooling events	1195	189	10	1757	1302	67
Average decrease (°C)	-0.79	-0.24	-0.200	-1.06	-0.407	-0.200

Table 2 shows that the heating effects of the CHT from surface infiltration (Control vs. NoSurf) are nearly the same as the CHT from both surface infiltration and migration between soils (Control vs. NoConv) in terms of frequency and mean increased temperature at each depth, indicating that infiltrative liquid flux from ground surface is the main source of the heating CHT and usually causes a mean temperature increase of about 0.9 °C, 0.4 °C, respectively, in 0.05 m and 1.05 m depth. While the Control vs. NoConv shows more frequent and drastic temperature decrease than Control vs. NoSurf, especially in 1.05 m depth (1302 cooling events and –0.407 mean temperature deviation in Control vs. NoConv, but only 189 cooling events and -0.244 mean temperature deviation in Control vs. NoSurf), which highlights that water flux between soil layers is more frequent in cooling the soil temperature.

Accordingly, we revised Section 3.3.1 about the shallow depths:

"The convective heat estimated in Control acts as an extra heat source during the spring melting periods when CHT occurred, the source that not only provided heat for the phase changes from ice to water, but also warmed the soils and caused an average increase in soil temperature of about 0.9 °C (shown in Table 2), compared to the NoSurf and NoConv results. The maximum temperature warming could reach 10 °C at a certain time."

"Apart from the imposed heating effect, an opposite cooling effect is observed at shallow depths, indicated as negative differences in Figure 6a and Figure 7a. Soil temperature decreased by an average of -0.79 °C and -1.06 °C (Table 2), respectively, when contrasting the results of Control with those of NoSurf and NoConv during the spring thaw and fall freeze periods, with extreme temperature reduction by up to -5 °C occurring in some durations."

"Figure 4 already shows that more cooling events were triggered by convective processes within the soils than by infiltration. It becomes even clearer by comparing Figure 7a showing Control-NoConv with Figure 6a showing Control-NoSurf. Table 2 shows that there are 1757 cooling events in the comparison between Control and NoConv, but only 1195 between Control and NoSurf."

We also revised Section 3.3.2 about the intermediate depths:

"Temperatures at these depths averaged 0.43 °C (Table 2) higher in Control than in NoSurf during thaw periods when CHT events occurred."

"In these cases, temperatures in NoConv surpassed those in Control by an average of 0.41 °C for each cooling event (Table 2), while temperatures in NoSurf surpassed those in Control by only an average of 0.24 °C (Table 2). The frequency of cooling CHT effects when comparing Control and NoConv (1302 times over the entire simulation period) was also several times higher than when comparing Control and NoSurf (189 times), indicating that liquid flux between soil layers exerts more cooling effects on soil temperature at intermediate depths than infiltrative flux does."

At last, we also improved the Abstract and Conclusions by replacing the maximum temperature disruption with the mean values.

RC1: Taking into consideration the above comments and questions, the paper needs more clarification on the mathematical formulation, application, and discussion with similar studies.

Authors: Thanks.

RC1: Minor

L45-48 …influenced. Influenced by what? Not clear. I suggest to re-write.

Authors: Done, this sentence has been re-written as:

"Given the current warming trends in most of the Earth's permafrost areas (Biskaborn et al., 2019), significant changes in permafrost dynamics are likely to occur, and the local ecosystem and environment have already been seriously influenced by regional hydrological and thermal changes caused by permafrost degradation (Cheng and Wu, 2007; Jin et al., 2009; Jorgenson et al., 2001; Tesi et al., 2016)."

RC1: L121-124 need a reference.

Authors: Done. We also have provided some more details about the reasons why the SHAW model outperforms the other LSMs, one is the detailed physics of CHT process and the other is the special iteration scheme for reducing the biases due to its complex physic basis:

"The SHAW model is one of the few land surface models (LSMs) that considers the detailed physics of the interrelated mass and energy transfer mechanisms, including precise convective heat transport processes of liquid water and vapor (Kurylyk and Watanabe, 2013), making it advantageous for demonstrating the important interactions between soil water dynamics and frozen soil thermal regimes in permafrost regions (Flerchinger et al., 2012). In addition, SHAW applies a special iteration scheme in which a time step is subdivided into multiple sub-time steps to control the error from the previous step in solving the mass and energy balance and to strictly enforce the mutual coupling of the hydrological and thermal processes (Flerchinger, 2000)."

RC1: In Table 1. Are any of the parameters been tuned during this study?

Authors: In this study, we used a Latin Hypercube sampling method to generate 1000 combinations of parameters, then we examined parameter sensitivity and identified the optimal values for the sensitive parameters for the Control (the original SHAW model) experiment. Only 4 parameters (i.e., saturated hydraulic conductivity, air-entry potential, saturated volumetric moisture content, and pore-size distribution index) were calibrated and the others were assumed to be the default values. The calibrated parameters in Control were consistently applied to the other two scenarios to make sure the parameter value won't influence the results. Since the Control scenario takes the full consideration of CHT and the other two are incomplete, comparing their outputs based on the same parameter values can filter out the sole CHT impact from the interrelated thermal transfer system. We have improved the description about this issue in Section 2.4:

"The most optimal parameter values from the 1000 combinations, as presented in Table 1, were consistently applied to all three scenarios designed in Section 2.2 to eliminate the influence of parameter values on the inter-scenario comparison."

In this revision, we also clarified how to do with the model parameters and their uncertainties, as requested by the other reviewer:

"We calibrated the four main hydraulic parameters (Table 1), i.e., saturated hydraulic conductivity, air-entry potential, saturated volumetric moisture content, and pore-size distribution index, relating to soil moisture in the model, while keeping the other soil parameters as default values. Data from 2008-2009 were used for calibration and 2010 for validation. The model was run with an hourly time step and the results were then

aggregated to a daily scale to facilitate comparisons and analyses. The ranges of hydraulic parameter values were roughly determined with reference to previously studies (Chen et al., 2019; Wu et al., 2018; Liu et al., 2013). To find the best parameter combination and measure model uncertainty, 1 000 independent parameter combinations randomly generated by the Latin hypercube sampling method in conjunction with the priori ranges. We restricted the values of sampling parameters in adjacent layers to assume that adjacent soil layers have similar textures. Then the 1000 combinations were used to drive the model one by one, and their outputs were compared and evaluated to determine the optimal parameter values for each soil layer. Two metrics, including the Nash-Sutcliffe efficiency coefficient (NSE) and root mean square error (RMSE), were used to quantify the performance of the parameter combinations:

$$NSE = 1 - \frac{\sum_{t=1}^{N}(O^t - M^t)^2}{\sum_{t=1}^{N}(O^t - \bar{O})^2} \quad (13)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(O^t - M^t)^2} \quad (14)$$

where O^t and M^t are the observed value and simulated value at time step t; $\bar{O}$ is the mean of the observations over the entire period; and N is the total number of time steps. Considering the interaction between soil temperature and soil moisture in a coupled system, the simulation accuracy of both variables is mutually suppressed, i.e., while the accuracy of one variable continues to improve by continuously optimizing its parameter value, the accuracy of the other decreases. Thus, we determined the optimal parameter combinations by balancing the performances for both soil temperature and moisture. In addition, the 95% probability bands (95PPU) of simulated soil temperature and moisture of all 1000 random parameter combinations were also counted, showing the range of distribution of results due to parameter degrees of freedom, to measure model uncertainty introduced by parameter selection at the TGL site."

And the related results (texts and revised Figure 2 below) are also provided here for your reference:

"Overall, both the 95PPUs and the optimal outputs confirm a good capability of the SHAW model to simulate the complex freezing and thawing processes in the active layer given reliable lower boundaries. Seasonal variations of both soil temperature and soil moisture in the active layer of the TGL were successfully captured. The 95PPUs of soil temperature associated with the 1000 parameter combinations are narrow in band and cover the observations well at each depth, indicating the good performance and low uncertainty of the SHAW model in modelling soil temperature at the TGL site. According to our experiments, saturated hydraulic conductivity is the most important parameter that effects the simulated soil temperature. Although the 95PPUs of the simulated UWC also roughly cover the observations, a wide band and overestimation at 0.4 m and 1.05 m depths relative to the observations indicate a large uncertainty in simulating UWC and call for a necessary parameter calibration. Saturated hydraulic conductivity and saturated volumetric moisture content were identified as the most important parameters controlling simulated UWC and were treated carefully. At the intermediate depths where low liquid contents were observed, optimal parameter values are picked from the random parameter combinations for these

layers that both simulate lower UWC and ensure good accuracy of the simulated soil temperature."

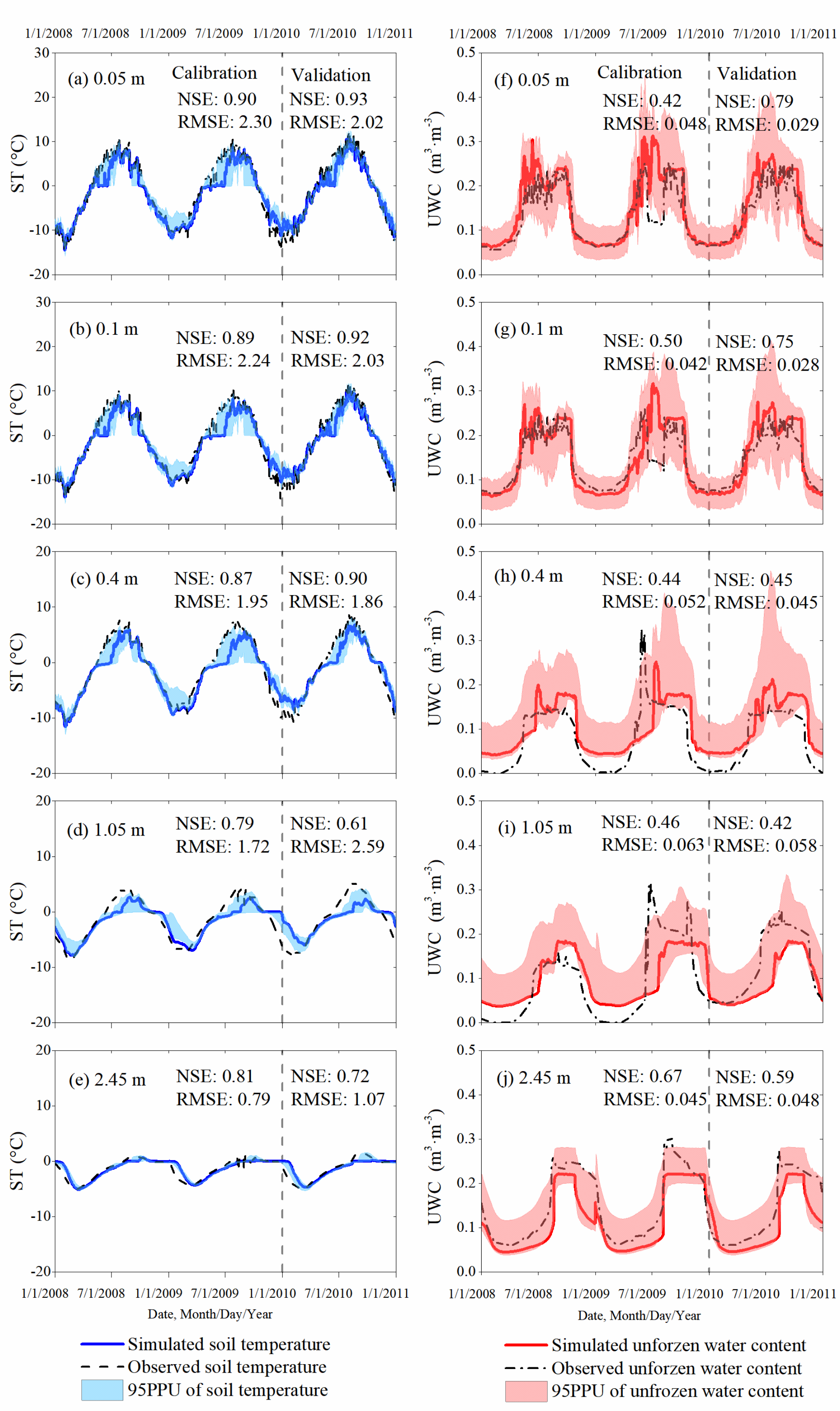

Figure 2 Simulated (solid lines) and observed (dashed lines) daily soil temperatures (ST; left panels) and unfrozen water contents (UWC; right panels) at 0.05 m (a and f), 0.1 m (b and g), 0.4 m (c and h), 1.05 m (d

and i) and 2.45m (e and j) depths at the Tanggula (TGL) site from 1 January 2008 to 31 December 2010. The simulated soil temperatures (solid blue line) and UWCs (solid red line) are the results with the optimal parameter values identified from the 1000 random parameter combinations. NSE: the Nash-Sutcliffe efficiency coefficient; RMSE: root mean square error. The 95PPUs of the model outputs are from all 1000 randomly generated parameter combinations.

RC1: On Figure 2. It is hard to tell the time of snowmelt.

Authors: We have replaced the Figure 2 in the initial manuscript (now Figure 3 in the revised manuscript) with a new figure in which the specific dates of snowmelt events have be mentioned. The new figure is presented here for your reference.

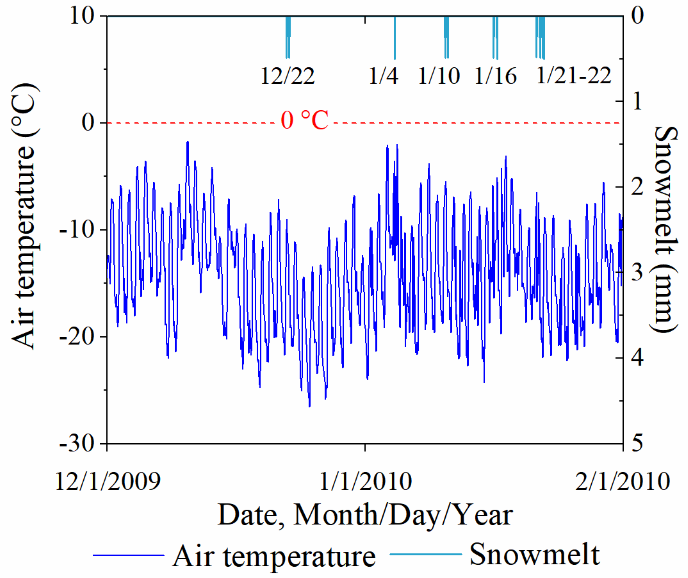

Figure 3 Unusual warm air temperature in January 2010, presumably related to overestimation of modelled soil temperature that month, and simulated hourly snowmelt, also influenced by air temperature. The dates (month/day) at the top of the figure indicate when the snowmelt events occurred.

RC1: Additional language improvements are needed as well.

Authors: Done. We revised the manuscript very carefully and we think the language has been much improved.