Reply to

Interactive comment on "Effects of Stratified Active Layers on the High-Altitude Permafrost Warming: A Case Study on the Qinghai-Tibet Plateau" by X. Pan et al. Anonymous Referee #2

We thank the reviewer for her/his insight comments and suggestions, which significantly enhance the quality of our paper. Regard to the suggested quantitative arguments and the implications of the findings, we have added them in the revised manuscript.

With regards to the major comments:

1. "*The formula for « thermal offset » and « surface offset » should be recall (in the introduction) for better clarity. In section 3.2, confusion is introduced about « thermal offset » : it was defined in the introduction as « TTOP – MAGST ». In section 3.2 it is approximated by « T(-2.18 m below surface) – MAGT » with MAGT quite different from MAGST. Please clarify.*"

As suggested, the thermal offset and surface offset are recalled in the revised manuscript. The "MAGST" was accidentally written as "MAGT" in that sentence. It was replaced with "MAGST" in the revised manuscript.

2. "*Section 2.2 is entitled : 2.2 Surface-subsurface monitoring scheme Subsection. « Scheme subsection » could be deleted from the title.*"

The "subsection" is removed.

3. "*The defined soil architectures in Section « 2.4.2 Simulation protocol » are not consistent with the caption of Fig 9 and the explanations of Section 3.6.1. Please make sure the Architecture definition is consistent in the whole document (maybe add a Table).*"

Thank you very much for pointing out this error. It is corrected in the revised manuscript and the Table 2 is also reformulated as appended.

4. "*P8 l 2, L31 : neither the model nor the effect are 'validated' in the current state of the paper. The comments below may give some sense to the validation of the effect through modelling.*"

We apologize for misusing the word "validate". It is replaced with "characterized".

5. "*Concerning the local λt/ λf ratio : Year 2008 is used as an illustration of typical annual conditions. Given that ground temperature and soil water content are being measured at this site since 2006, stepping back from Year 2008 and bringing an interannual perspective would strenghen the paper's conclusion. I at least recommend a Table with the maximum λt/ λf value over the upper 2.18 m of the soil for each year with observations.*"

Appended table 3 is added, and two sentences are inserted as "The inter-annual variation of the maximum λ_t/λ_f in the profile is listed in Table 3. In most years, it is very close or over 1, e.g., 2008 and 2009. The smaller value 0.90 in 2013 is attributed to the wet year with extraordinary rainfall."

6. "*Concerning the impact of the λt/ λf ratio on permafrost warming :*

o Fig 6 could provide the vertical profiles for λt and λf with λm=2.5 W/m/K, in support of the assessment : «In order to exceed the ratio of 1, the seasonal liquid water content has to fall below a certain threshold, which depends on soil thermal conductivity and water content in thawed state. For instance, the soils with high thermal conductivity of soil matrix will need larger liquid water content reduction than that of the soils with small thermal conductivity of soil matrix.»"

The λ_t and λ_f in Figure 6 were calculated with λ_m=5.0 W/m/K. It shows the maximum ratio $\lambda_t/\lambda_f>1$ at the depth of around 1 m. In most years, it is very close or over 1 (Table 3).

In our simulations, λ_t/λ_f are relative lower than the observed ones. Given current parameterizations, it is difficult to reproduce comparable hydraulic and thermal dynamics as observed in the active layer. Particularly, the used hydraulic parameters in our model are just determined from some statistical relationships, which are rather rough. Therefore, our simulations can only capture the seasonal pattern of soil moisture reduction, but the absolute amount of seasonal soil moisture amount, as well as water content in thawed state, are still not good enough. Since λ_t/λ_f is very sensitive to the seasonal reduction amount and soil moisture content in summer, the simulated λ_t/λ_f is relative low. That's also the major reason for the small differences of permafrost regimes among A1, A2 and A3 (Figure 12). Concerning the relative low impact of soil moisture reduction on λ_t/λ_f for the simulations using λ_m=5.0 W/m/K, simulations using λ_m=2.5 W/m/K are better for visualizing the effects of stratified active layer on permafrost warming.

o "A high λ_t/λ_f ratio is advanced as an important argument for an enhanced permafrost warming rate at the observation site. However, Fig. 12 is the only illustration supporting this thesis (as modelling - Fig 8 - fails to reproduce the observed warming) ; it shows that permafrost warming rate is enhanced in the A3 configuration ; the authors explain that this is due to higher λ_t/λ_f ratio, but this ratio is unfortunately never explicited. I highly recommand adding the mean interannual λ_t/λ_f for each of the 10-year periods preceeding the selected years of Fig. 12, and for each soil architecture. This would make the paper's main argument less vague. This point is a Major Comment."

The decadal mean λ_t/λ_f are added in append Figure 13. The simulations in Fig. 8 fail to reproduce the observed warming because of the passable representation of the land-atmosphere coupling in winter (see more details in reply for #RC 1.) as well as limited representation of hydraulic and thermal dynamics in the active layer. However, simulations in Figure 12 support our hypothesis that the stratified active layer with seasonal soil moisture reduction enhances permafrost warming, although they are not so evident. The added Figure 13 further consolidates it. Overall, the active layers with λ_m=5.0 W/m/K (left column) have higher values of λ_t/λ_f than that with λ_m=2.5 W/m/K (right column), they also lead higher warming rates (Figure 12). However, the smaller differences among the architectures in the left column indicate that the impacts of the seasonal soil moisture reduction on λ_t/λ_f are not as significant as that in the right column. Generally, the A3 have higher values of λ_t/λ_f than the others in both columns at the early stage, and they also have relative higher warming rates.

o "P 10 l 13 : the formulation could be improved (like : high -> higher)"
Done.

7. "P*5 l 30 and P8 l 24 : a crucial thing is to know whether the annual cycle of precipitation in the chosen downscaled projections, is still monsoon-like (as today) or shifts to different patterns in future climate. The authors mention that the projected rainfall may not be accurate. However, given the importance of the annual rainfall pattern on the site specific sub-surface thermal dynamics,* ***more investigations*** *on the projected precipitation pattern in the chosen downscaled climate product is needed, in support of the assessment of the impact of λ_t/λ_f on the warming. This point is a Major Comment.*"

We agree with that the monsoon-like precipitation pattern is crucial for the site specific sub-surface thermal dynamics. The prevailing view for the Asian summer monsoon is caused by the elevated heat source driven by the QTP (e.g., Yeh et al., 1957, Yanai et al., 1992). Observations of energy fluxes over the QTP show climate change may led to a shift of monsoon intensity (Duan et al., 2011). However, the Asian monsoon mechanism might not disappear in the near future due to the dominant factor of high elevated topography. Although the monsoon precipitation intensity might shit a little bit, the annual rainfall pattern will still lead to a notable seasonal soil moisture reduction, as well as high ratio of λ_t/λ_f in the active layer.

In addition, as explained for the general comments this study is aim to address the effects of stratified active layers on the high-altitude permafrost warming, the monsoon precipitation pattern is a precondition. The selected climate model does reproduce a monsoon-like precipitation pattern for the whole period (1850-2100). It assumed that the monsoon was not changed in the future. Since we are not aim to predict the permafrost warming but to test our hypothesis that the stratified active layer enhances permafrost warming due to the high ratio of λ_t/λ_f, the selected climate model data is reasonable.

To make clarify the persistence over time of the hypothesis, we add a paragraph to clarify this issue in the revised manuscript as follows.

" In addition, the effects of stratified active layers on permafrost warming also evolve in time. As a key role in enhancing λ_t/λ_f, the seasonal soil moisture reduction can be influenced by changes in precipitation pattern and active layer thickness. The Asian summer monsoon, caused by the elevated heat source driven by the QTP (e.g., Yeh et al., 1957, Yanai et al., 1992) may not disappear in the near future, but the monsoon intensity might shift due to climate change (Duan et al., 2011). In addition, change in active layer thickness will influence the suprapermafrost water level, which is essential to the soil water content distribution in the active layer. Given a monsoon dominated precipitation pattern in the projected climate model data, differences in the evolution of λ_t/λ_f in the shallow layers (0-1.5m) are shown in Fig. 13. Compared to the same soil architectures but λ_{sp} = 2.5 W m^{-1} K^{-1}, the decadal mean λ_t/λ_f in the left column are higher than that corresponding in the right column. But the differences of λ_t/λ_f amount the architectures are bigger in the right column. Besides, the highest values of λ_t/λ_f in A3 are bigger than the other two from 1980s to 2040s, then they gradually become smaller. Generally, the shrinking differences in decadal mean λ_t/λ_f among the three architectures indicate that the effects of the stratified active layers on permafrost warming are significant in the early state of permafrost degradation, and they will decrease afterward. This is one major reason for the small differences in thermal regimes of the three architectures in Fig. 12."

Yeh, T.C., Luo, S.W., and Chu, P.C.: The wind structure and heat balance in the lower troposphere over Tibetan Plateau and its surrounding, Acta Meteor. Sin., 28, 108–121, 1957.

Yanai, M., Li, C., and Song, Z.: Seasonal heating of the Tibetan Plateau and its effects on the evolution of the Asian summer monsoon. J. Meteor. Soc. Japan, 70, 319–351, 1992.

Duan, A., Li, F., Wang, M., and Wu, G.: Persistent weakening trend in the spring sensible heat source over the Tibetan Plateau and its impact on the Asian summer monsoon, J. Climate, 24, 5671–5682, 2011.

Technical Corrections

1. "- *Very frequently the authors confuse « whereas » with « while » or « in the opposite ». (p4 l 23 ; p5 l 14 ; p6 l 13 and l 24 ; p9 l 28 ; ...)*"

   Done.

2. "- *P2 l 14 : basing -> based*"

   Done.

3. "- *P3 l 15 : humility -> humidity*"

   Done.

4. "*P4 l 2 : incomplete sentence*"

   It is rephrased as "It invokes a relation between the soil freezing characteristic and the soil water characteristic and assumes a rigid soil scheme without change in volume for water phase transition (Kurylyk and Watanabe, 2013)".

5. “*P5 line 13 to 16 : unclear, please reformulate*”
   It is moved and merged into the introduction section.

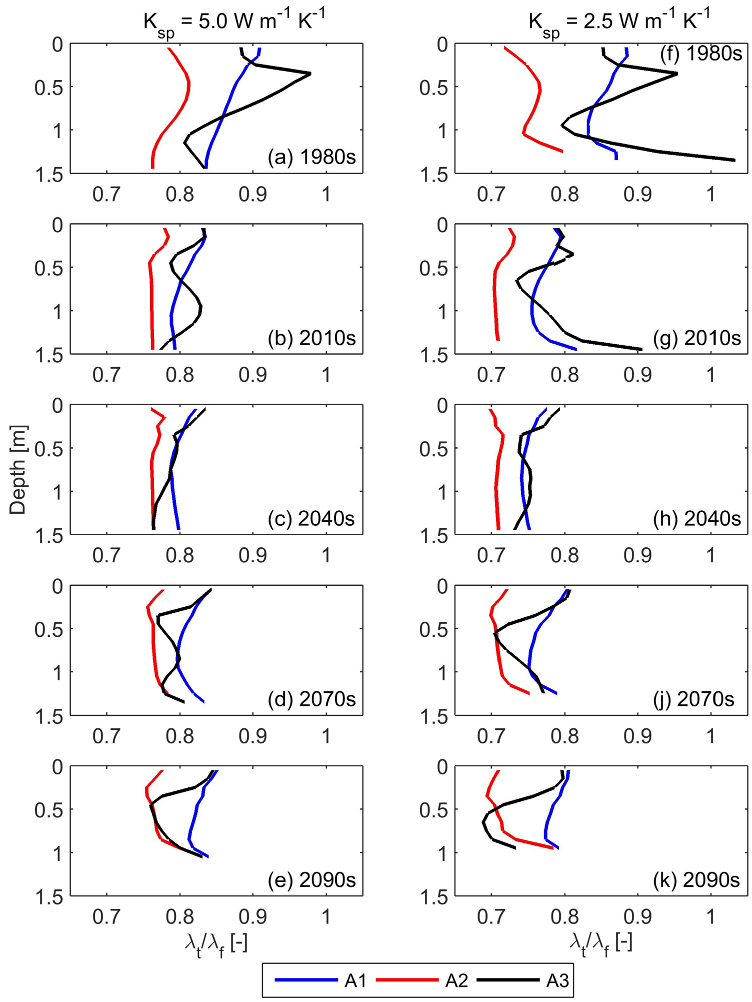
6. “- *P9 l 18 : till talik -> when talik*”
   Done.

Table 2. Six simulations with different combinations of soil architecture and thermal conductivity of soil particles (λ_{sp}) for the shallow layer (0-3.0 m). A1, A2 and A3 stand for three types of soil architecture for the shallow layer. I and II stand for the two types of soil properties in Table 1.

λ_{sp} / W m^{-1} K^{-1}	Architecture		
	A1: I	A2: II	A3: I + II
5.0	1	2	3
2.5	4	5	6

Table 3. Inter-annual variation of the maximum seasonal thermal conductivity ratio (λ_t/λ_f) in the monitoring profile. * Hydrological year: from May 1 to the next April 30.

Year*	2007	2008	2009	2010	2011	2012	2013
λ_t/λ_f	0.99	1.01	1.01	0.97	-	1.00	0.90



Append Figure 13. Comparison of the influence of soil architecture and thermal conductivity of soil particles (λ_{sp}) on the seasonal thermal conductivity ratio λ_t/λ_f in the shallow active layer over the period from 1980 to 2100. (a) - (e) Decadal mean λ_t/λ_f of A1, A2 and A3 with a high λ_{sp} = 5.0 W m^{-1} K^{-1} at selected decades; (f) - (j) the same as (a) - (e) but with a low λ_{sp} = 2.5 W m^{-1} K^{-1}.