Response to interactive comment on "The influence of climate and hydrological variables on opposite anomaly in active layer thickness between Eurasian and North American watersheds" by H. Park

park@jamstec.go.jp

Dear Referee #1, Thank you very much for your valuable comments which will help to improve our manuscript. Our answers to your comments and suggestions are described at the below.

Specific comments

Some words and statements used about the effects of hydrology seem exaggerated. For example, Lines 8-9 in abstract "Time series of ALT in Eurasian watersheds showed generally increasing trends, while ALT in North American watersheds showed ***decreases.*** *An* ***opposition*** *of ALT variations . . . ". For the entire period (1948-2006), ALT in Mackenzie and Yukon basins also increased although not so large. The difference occurred only after 1990. Lines 19-23 in abstract, these statements are too speculative and general, and seem exaggerated. Snow and soil moisture conditions will affect ALT in addition to air temperature, whether their effects can* ***override*** *the effects of air temperature depends on many conditions, including the rates and seasonality of the changes in air temperature, snow conditions and soil moisture, and the time period considered. In addition, snow and soil moisture also related to air temperature. Following are some specific points which may complicate these conclusions.*

As you mentioned, ALT in Mackenzie and Yukon watersheds showed increasing trends during 1948-2006 although not statistically significant and not so large (Table 1). Therefore, the expression in Abstract was revised as "Time series of ALT in Eurasian watersheds showed generally increasing trends, while the increase in ALT in North American watersheds was not significant. However, ALT in North American watersheds was negatively anomalous since 1990 when the Arctic air temperature entered into a warming phase. The warming temperatures were not simply expressed to increases in ALT." The final statements in Abstract were deleted. Instead, a new description was added "The different ALT anomalies between Eurasian and North American watersheds highlights increased importance of the variability of hydrological variables."

1) In your analysis, you used the period 1991 to 2006. The annual thaw index (ATI) is very low in 1991, which promote the increasing trend in ATI. If you start the period several years earlier or later, the trend will be weaker or even declining. Observations from 1998-2005 in Mackenzie Basin show ALT generally have positive responses to ATI at all the eight observation sites (Smith et al., PPP, 20: 201-220, 2009).

The trend could change dependent on the period considering for the analysis. For example, for the period of 1998–2005, you mentioned, the simulated ALT in Mackenzie exhibited slight increasing trend. Furthermore, as another example, the ALT of the Mackenzie during 1996–2006 obviously shows increasing trend. However, it has been reported that the warming trend of Arctic air temperature was very strong since about 1980 (Bekryaev et al., J. Clim., 23, 3888–3906, 2010). In our analysis, in reality, summer air temperature clearly indicated the increasing trend. It has been generally known that air temperature, or annual thawing index (ATI) is a major impact factor on ALT. However, ALT of the Mackenzie since 1990 decreased inconsistent with the trend of ATI. Therefore, the period of 1991–2006 that the opposition of ALT between Lena and Mackenzie watersheds was mostly clear was selected for the analysis.

2) Observed ALT in 1998 was significantly deeper than in other years and it is due to the unusually warm year (Smith et al., PPP, 20: 201-220, 2009; Smith et al., 2001: The response of active-layer and permafrost temperatures to the warming during 1998 in the Mackenzie Delta, Northwest Territories and at Canadian Forces Station Alert and Baker Lake, Nunavut. Geological Survey of Canada Current Research 2001-E5, 8p). Early snow melt can promote deeper ALT as well. Your modeled ALT in 1998 was not very deep and the snow depth in Jan-March was very shallow. The under-estimation of ALT in this extreme year could affect your statistics.

Despite the fact that the Annual Thawing Index in Mackenzie in 1998 was extremely high, ALT was near the normal value (Fig. 5e). The ALT displaying on Fig. 5 represents an averaged value for entire grids within the Mackenzie watershed. Therefore, it never means that ALT in all of the grids within the watershed is not deepened. Seeing the spatial distribution of ALT, for instance during the period 1991–2000 (Fig. 4d), ALT in the southern regions tends to be deeper than the average. Smith et al. (2009) also observed that thawing depths at southern sites significantly correlated to thermal forcing. Meanwhile, the simulated ALT over the northern regions generally shows the negative anomaly (Fig. 4d). The northernmost regions are characterized longer freezing period compared to the southern regions. The strongly frozen ground caused by the shallowest snow depth (Fig. 4b) can influence the thawing of ground during summer season, implying that the modeled soil temperature sensitively responded to the winter snow condition. Moreover, the soil dryness during summer season limits heat conduction into the soil, contributing to lower ALT. It seems that these regional biases affected to the mean ALT of the watershed.

3) You claim that the pre-thaw season soil moisture also affect ALT (Line 12-13, P 2556, and other places). The linkage is not clear in your analysis. The soil moisture you used for analysis is from June to August. Figures 6b and 7e show consistent positive responses of ALT to soil moisture. As you said, low soil moisture reduces thermal conductivity while high precipitation may cool the soil as well (P2556). For your conclusion, you need to separate the effects of summer precipitation and the pre- thaw season condition on soil moisture. Clarify or revise it.

In the manuscript, no data were provided to support the influence of soil moisture in pre-thaw season on ALT. Thus, the related description was deleted or revised on the new manuscript. In Conclusions, the description associated with pre-thaw season soil moisture is also revised as "This implies that the larger summer precipitation weakened atmospheric thermal forcing, and hence lowered ALT."

In Figure 6, I feel the response of ALT to soil moisture is as consistent as to annual thawing index. Is this related to your definition of soil moisture used for analysis? Please check. I am doubtful of such a strong correlation. Adding some explanation or supporting observations would be useful.

Soil moisture is defined as only liquid water averaged during June to August in the upper soil 1.6 m, excluding ice amount within the soil depth. When ALT is deepened, the melted ice is added as soil moisture that in turn contributes to higher ALT. Therefore, soil moisture at the deeper soil layers can keep relatively higher values. In reality, the correlation between the soil moisture and ALT was good at the regions where the mean ALT was generally less than 1.6 m (Fig. 1a). The regression likely represents SM variations implicated in the formation of ALT.

We have been observing soil temperature and moisture at several sites around Yakutsk, eastern Siberia. The observed data indicated the positive relationship between soil temperature and moisture, regardless of vegetation and soil type (Ohta et al., Agric. For. Meteorol., 148, 1941-53, 2008; Iijima et al., PPP., 21, 30-41, 2010).

Thus, the above descriptions were added on Line 14, P2551 as "Interestingly, the regression displays higher values over regions that the mean ALT is generally less than 1.6 m (Fig. 1a). When ALT increases, the melted ice is added as soil water, thereby higher SM that in turn contributes to higher ALT. The regression likely represents SM variations implicated in the formation of ALT. Longer observations around Yakutsk, eastern Siberia indicated that soil temperature was positively related to the variation of soil moisture, regardless of vegetation and soil type (Ohta et al., 2008; Iijima et al., 2010)."

Minor corrections

Line 10, P. 2540. Delete the comma after accumulation.

The comma was deleted. It seems that you mentioned not Line 10 but Line 13.

Line18-19, P 2541. "under the present-day climate" is not needed.

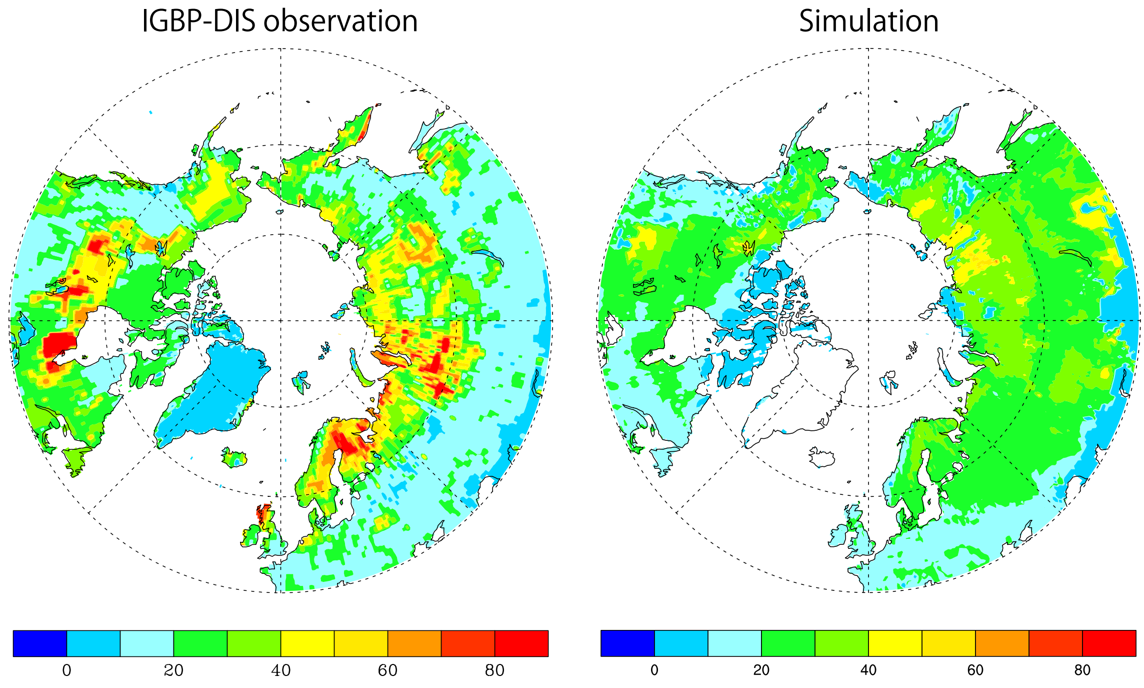
That was deleted.

Line 2, P 2545. Delete "wind speed"? It seems no wind speed in this dataset according to the following sentences.

“wind speed” was deleted.

Line 22. The initialization assuming no snow and no soil carbon. Is there no snow on the first day or the entire beginning years? If so, the modeled soil temperature will be under-estimated. The model simulated the accumulation of soil C in 420 years? If so, how good is the modeled soil C distribution? Does soil C change during 1948-2006?

The condition of ‘no snow’ was applied on only the first day. When precipitation event occurred after the day, snow had began to accumulate. The simulated soil C (kg/m2) is present. When compared to the soil C of IGBP-DIS (Global Gridded Surfaces of Selected Soil Characteristics, http://daac.ornl.gov/SOILS/guides/igbp-surfaces.html), the model generally tends to overestimate soil C in the sub-Arctic regions while to underestimate that in the northern Arctic regions, especially in Scandinavian peninsular, north-western Siberia, and Canada. The soil C was changed during the simulation period, dependent on productivity and decomposition.



Section 3.1.2 and 3.1.3. The modeled soil temperature has a low bias of 2.1C, especially for the Russian climate stations. The observed ALT at these climate stations

seem no systematic difference although they are scattered, and the model over-estimated ALT for most of the CALM sites and the sites in Mackenzie basin.

It seems that the overestimated ALT for CALM site and the sites in Mackenzie basin was associated with the underestimated soil C. In reality, the model overestimated soil temperatures for the sites in Mackenzie basin (Fig. 3a). In case of Russian meteorological sites, the underestimation of soil temperature by the model was more significant in the sites that the observed soil temperature was ＞0℃ (Fig. 3a), probably corresponding to non-permafrost region and relatively warming southern permafrost regions, in which the model overestimated soil C. Meanwhile, the comparison between the observation and simulation for the sites of ＜0℃ (i.e. corresponding to probably eastern Siberia, Fig. 3a) shows large scattering similarly as found in the comparison of ALT. Therefore, it is considered that the tendency of simulated soil temperature was systematically expressed to the ALT.

Lines 25-27, P2547. This sentence is repeating the previous one.

The sentence was deleted.

Line 1, P 2549. Climates, delete ‘s’.

‘s’ was deleted.

Line 3, P 2549. “transfer” probably should be “received”.

‘transfer’ was changed to ‘received’.

Line 12, P2549: “for” to “from”.

It was changed to ‘from’.

Line 14, P 2549. What is the unit of the soil moisture? You used mm in Figure 4. According to this definition, increasing ALT will directly add more liquid water as soil moisture.

The unit of the soil moisture is mm, which was converted from volumetric water content (%) for liquid water and soil depth (m×1000). The increasing ALT could result in more soil moisture, which is likely more significant at deeper soil.

Line 22, P 2549. "in the Manitoba region". It seems not in Manitoba. Probably should say "in some southern permafrost regions in Canada".

It was revised to 'in some southern permafrost regions in Canada'.

Line 25, P2549. Delete the first "century".

'century' was deleted.

Line 8, P 2550. "Mean and time series of ALT.." Revise to "Time series of mean ALT ..."

It was revised to 'Time series of mean ALT …'.

Line 20, P 2551: "not" should be "not only"?

It was revised to 'not only'.

Line 9, P2552. 20mm should be 20cm?

Yes, 20cm is right, which was revised.

Line 8, p2553. "ones" should "that"

It was revised to 'that'.

Figure 8 and the discussions are complicated and somewhat repeat Figure 7. probably not needed.

Figure 8 was deleted, and the related description was also removed from the discussion section.

Discussion section. The changes of precipitation and its impacts on soil moisture are very important, probably should be described in the results section.

As you suggested, the changes of precipitation and its impacts on soil moisture were moved to the results section as "Soil moisture is greatly influenced by precipitation. Figure 8 shows time series of summer (June to August) precipitation for the Lena and Mackenzie, exhibiting large inter-annual variability.

It is found different trends for the precipitation, decreasing in the Lena and increasing in the Mackenzie although the trends are statistically not significant. Precipitation of the Mackenzie since 1970 was positively anomalous except for 1990s, while Lena generally ranged below the average since 1980. SM tended to respond positively to the precipitation (Fig. 7b). However, the anomaly of precipitation was not simply expressed to the same anomaly for SM of the two watersheds. SM of the Lena was positively anomalous during the recent two decades (Fig. 7b), despite the negative anomaly of precipitation (Fig. 8). On the contrary, SM of the Mackenzie indicates negative, or normal state (Fig. 7b). Precipitation contributes to reduce soil dryness. On the other hand, larger precipitation cools soil surface and limits heat conduction into the soil, thereby lowering ALT. In reality, summer precipitation was negatively correlated with ALT in both the Lena (r=-0.24, $p < 0.08$) and Mackenzie (r=-0.18, $p < 0.18$). Lower ALT decreases the melt of ice, and hence lowers SM."

Line 14-15, P 2558. Too general and not related to the paper.

The description was deleted.

Figure 6. checking the units in the caption. Indicating the duration for calculating the linear regressions.

The unit was described newly. The duration for the calculation was added to the figure caption.

Figure 7c. "SD" should be "SND"

It was revised to 'SND'.