Deviations in gridded field measurements of ground temperature and active layer thickness in Wudaoliang Basin, Qinghai-Tibet Plateau

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Challenges from North to South
Des défis du Nord au Sud

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ABSTRACT
Ground temperatures were measured with 60 boreholes at four study sites (1, 2, 3, and 4). Under the similar climate condition, the ground surface temperatures in the same site from 15 boreholes were not similar. There is a maximum difference of 2.4°C at site 1 (alpine meadow with rock grids), 2.6 °C at site 2 (alpine meadow), 3.0 °C at site 3 (transitional area), and 3.1 °C at site 3 (alpine grassland), respectively. The active layer thickness measured from 15 boreholes is also have a maximum deviation of 118.0 cm at site 1, 78.5 cm at site 2, 64.0 cm site 3 and 65.0 cm site 4. The climate changing, soil moisture content loss and the environmental variables (thermokarst, strong sand wind, and vegetation degeneration) may be the main reason for these deviations, which should be better evaluated when mapping the permafrost spatial distribution and assessing local factors influence.

RÉSUMÉ
Les températures du sol ont été mesurées avec 60 forages à quatre sites d'étude. Avec les mêmes conditions climatiques, les températures de surface du sol au même site à partir de 15 forages ne sont pas similaires. Il y a une différence maximale de 2,4 ° C sur le site A (prairie alpine avec des grilles de roche), 2.6 ° C sur le site B (pré alpin), 3,0 ° C au niveau du site C (zone de transition), et de 3,1 ° C sur le site D (prairie alpine), respectivement. L'épaisseur de la couche active mesurée à partir de 15 forages a également un écart maximal de 118,0 cm au site A, 78,5 cm au site B, 64,0 cm au site C et 65,0 cm au site D. Le changement climatique, la baisse de la teneur en eau et les variables environnementales (thermokarst, fort vent de sable, et la dégénérescence de la végétation) peuvent être les principales raisons de ces écarts et devraient être mieux évalués lors de la cartographie de la répartition spatiale du pergélisol et de l'évaluation de l'influence des facteurs locaux.

1 INTRODUCTION

As a product of the interaction between earth-atmosphere systems, the feedback of permafrost is much sensitive to climate change and environmental disturbances (Henry and Smith, 2001; Smith and Riseborough, 1996; Smith and Riseborough, 2002). Permafrost spatial distribution is determined by macroclimate, whereas the regional permafrost distribution is also conditioned by the different microreliefs, such as the type of vegetation and soil (Williams and Smith, 1991). In Candan, a wide variation in mean surface temperature over a small area in the Mackenzie Delta was found that differences in microclimate affect both the annual range in surface temperature and mean annual surface temperature (Smith, 1975). The effect of peat lands on permafrost stability has been investigated and results suggest that local processes mediate the effects of regional climate (Camill and Clark, 1998). In the Yukon-Tanana, Canada, the relationship between vegetation types in dry lake basin and the thickness of the seasonally thawed zone above the permafrost has also been studied in 1974 (Dingman and Koutz, 1974). Warming has been observed in the Qinghai-Tibet Plateau (QTP) and the trend is higher than the average global warming (Liu and Chen, 2000). The latest climate forecast shows that air temperature in QTP may rise 2.2 to 2.6 °C by 2050 (Qin et al., 2002). Permafrost in QTP is sensitive to climate and ecotope changes. Influences of sand layers and vegetation on ground temperature are dual (Huang et al., 1993; Wang and Xie, 1998; Wang and Zhao, 1999). In the interior-eastern QTP, the studies show that ground temperatures in permafrost affected by local environmental factors such as vegetation coverage, snow cover, sand layers and surface water/moisture conditions, however, these influences are dual in that they can increase or decrease ground temperatures under certain circumstances(Jin et al., 2008; Lv et al., 2008). Along the Qinghai-Tibet Highway (QTH) permafrost regions, permafrost distribution varies in regions with geologic landforms, vegetation type and hydrologic conditions even under the same climatic conditions (Pang et al., 2011).

Although these researches have revealed the relationship between micro-environment and ground temperature in permafrost regions, there is little information about the temperature of spatial variation of permafrost and repeated measurements aiming to the uncertainty for permafrost simulation at small-scale (Rise borough et al., 2008). We choose the Wudaoliang Basin (WB) as the study area, which is located in the northern side of the QTP (N35°11.903′; E93°5.061′; H4612 m) (Figure 1). According to the weather station, the mean air temperature was -4.5 °C with a maximum temperature of 10.4 °C to a minimum temperature of -21.1 °C from 2012 to 2014. The geological conditions in the study area are similar. This paper continue the work published earlier this year by Lin et al. (2015) and we have more field temperature data. Here we presents the results of the fine grid temperature measurements, including air and surface temperatures, as well as ground temperatures down to about 5 m depth. The purpose of these measurements is to provide a more objective and understanding of the importance of the ground surface condition variability on permafrost monitoring in a small scale region, and analyse the deviations detailedly in each site.

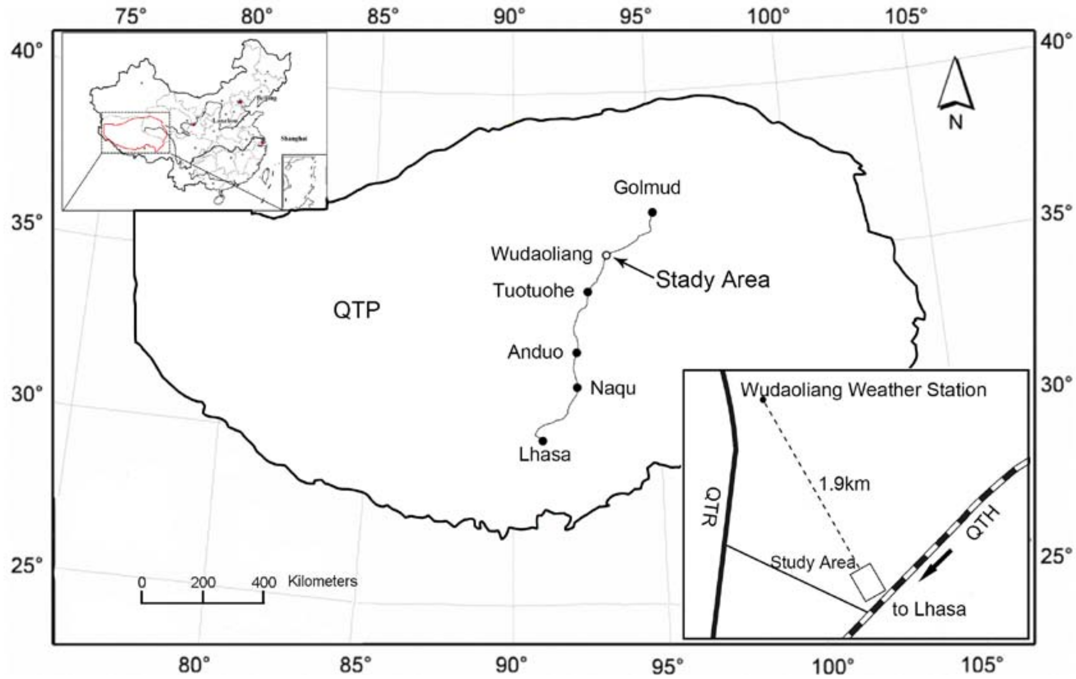

Figure 1. The study area in the Qinghai-Tibet Plateau.

2 METHODOLOGY

In this paper, we investigate permafrost conditions at four sites located across the grassland and meadows (at a scale of about 1 km^2) in WB, along a 1 km long section approximate perpendicular to the Qinghai-Tibet railway (QTR). As presented in Figure 2, the four sites are site 1 - an alpine meadow with rock grids and high vegetation coverage (⩾60%), site 2 - an alpine meadow with high vegetation coverage (⩾60%), site 3 - a transitional area between these two vegetation units with medium coverage (45 ~ 60%), and site 4 - alpine grassland with low coverage (10~30%). Between August and October 2011, 60 boreholes were drilled at the four sites to 5 m depth. The separation distance between each boreholes is 5m, forming a 10×20×5 m three-dimensional grid at each site. Thermistor cables with 23 sensors were placed in each borehole, protected by a PAP (Polyethylene-Aluminum composite). The spacing of the thermistors was 0.05 m within the upper 0.3 m, 0.1 m between 0.3 and 0.5 m, 0.25 m between 0.5 and 3 m, and 0.5 m below 3 m. The thermistors, with a precision of ±0.02°C, were manufactured and assembled by the State Key Laboratory of Frozen Soil Engineering, Chinese Academy of Sciences. At each site, three soil moisture smart sensors were installed at 0.5, 1.0 and 1.5 m depth in August 2010. A weather station was installed near site C in July 2011. Data collection began in July 2011 with measurements recorded every 4 hours. Instrumentation details can be also found in Lin et al.(2015).The analysis of the data was from 2012 to 2014, including all 60 boreholes. There were 55 boreholes data in Lin et al. (2015) because of the equipment failure that was renovated in 2015.

Figure 2. Geomorphic conditions of monitoring sites. (A) Site 1, alpine meadow with a rock grid; (B) site 2, alpine meadow area; (C) site 3, a transitional area between alpine meadow and sparsely vegetated ground; and (D) site 4, sparsely vegetated ground. (The pictures were taken on August 10, 2014)

3 RESULTS

3.1 Ground Temperature

We observed the ground temperatures from the surface to 5 m depth from 2012 to 2014. The soil surface temperature (T_s) was measured from the sensors at 5 cm below the ground surface（e.g. Karunaratne and Burn, 2004; Karunaratne, 2003; Klene et al., 2001; Lin et al., 2015). The mean T_s of 15 boreholes in each site from 2012 to 2014 was summarized in Table 1. But there is little law among each site. In addition, from the Figure 3, the annual mean T_s varied between boreholes at the same site, as well as with the time from 2012 to 2014. At site 1, the mean T_s of each borehole ranged from -2.4(2014) to 0.5(2013) °C, and the maximum difference between 15 boreholes was 2.4 °C (2013). At site 2, the mean T_s ranged from -2.1°C (2014) to 1.0 °C (2013), and the maximum variation between 15 boreholes reached 2.6 °C (2014). At site 3, the maximum deviation reached 3 °C with the mean Ts from -2.4 to 0.5 °C (2014). For site 4, the maximum variation was 3.1 °C (2013) and the T_s was -2.7 ~ 0.4 °C (2013).

Frequency histograms of ground temperature in 2014 at four sites for different depths are presented in Figure 4. At all sites, there are non-Gaussian temperature distributions at soil surface, with most values uniformly distributed around 0 °C from -14 °C to +14 °C. Near the surface of permafrost, there are better Gaussian temperature distributions at site 3 and 4 than site 1 and 2. With the depth increasing, the ground was frozen and the temperature was relatively stable.

Table 1. Annual mean soil surface temperature (T_s/ °C) at 5 cm depth, the standard deviation (SD), maximum T_s (Max/ °C) and minimum T_s (Min/ °C) of 15-borehole in the four sites from 2012 to 2014.

Site	1			2			3			4		
Year	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014
T_s [1]	-1.3	-0.6	-1.1	-0.7	-0.8	-1.1	-1.1	-0.7	-1.2	-0.3	-1.5	-0.9
SD	7.8	8.2	7.9	7.6	8.2	8.1	8.2	9.1	8.5	8.2	8.8	8.2
Min	-16.4	-16.7	-16.5	-14.3	-16.3	-17.3	-16.8	-18.5	-18.1	-16.3	-17.8	-16.7
Max	13.7	17.1	14.7	12.9	18.2	13.3	15.0	18.3	15.0	16.4	18.6	17.1
Count	5475	5444	5475	5490	5506	5476	5490	5475	5444	5521	5475	5475

[1] There are some differences with Lin et al. (2015) because here we obtain the mean values by every day, but Lin et al. calculated the mean values by every other five days which means that the count is different.

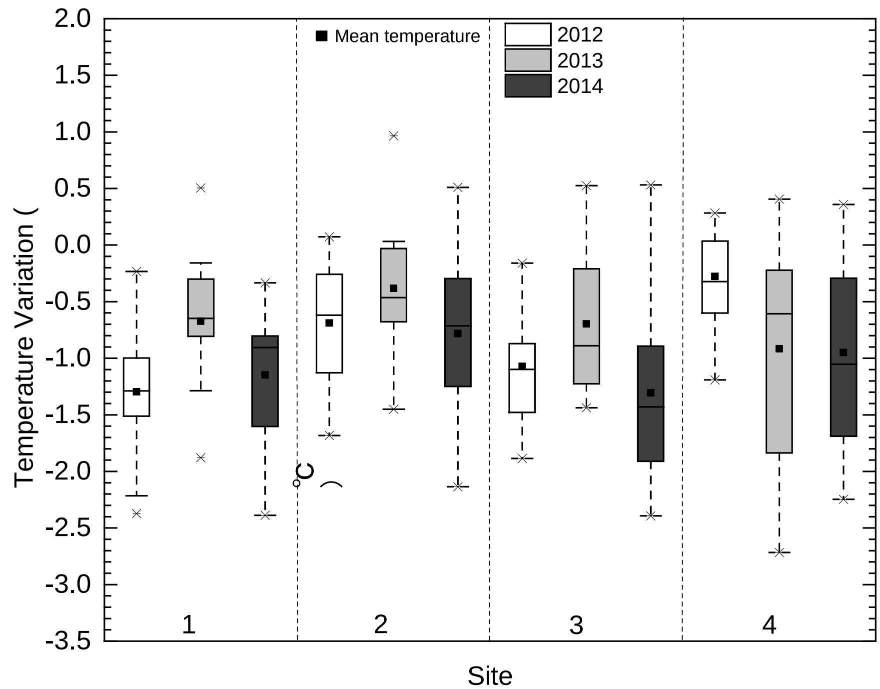

Figure 3. Boxplots of the annual mean T_s of 15 boreholes at each site from 2012 to 2014.

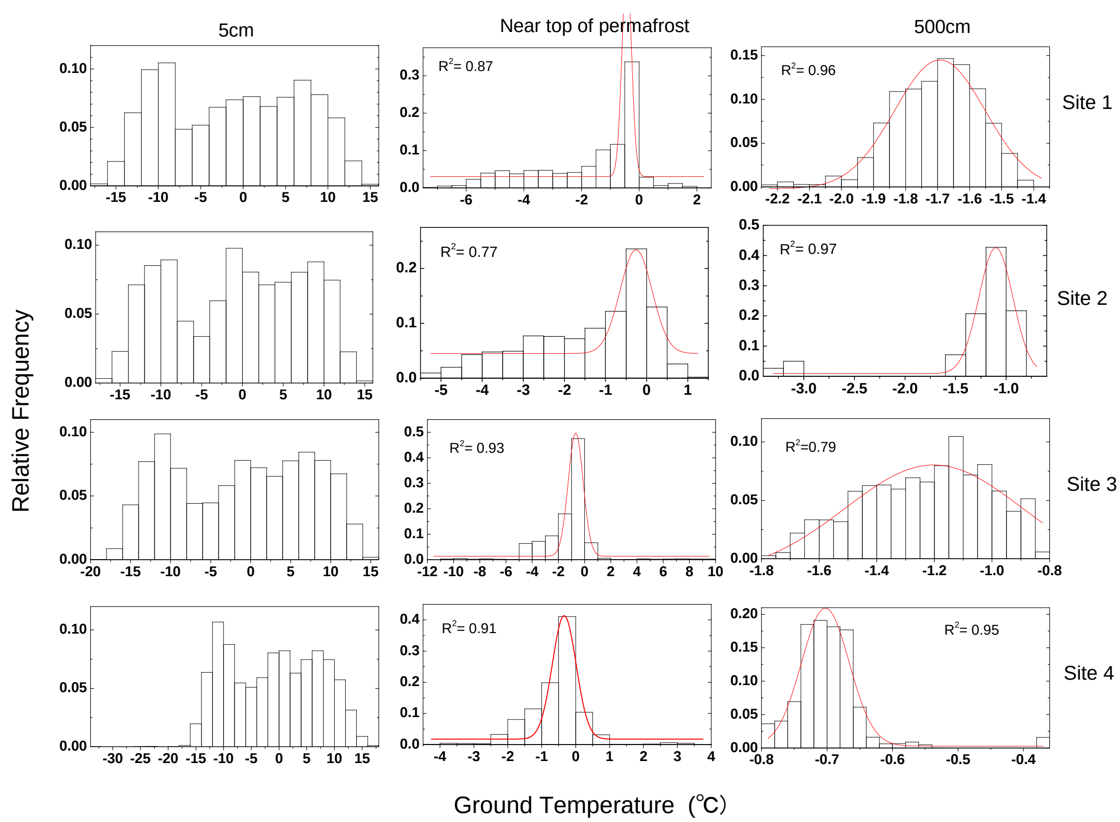

Figure 4. Frequency histograms of daily temperatures from 15- borehole for different depths at each site (in the year 2014). Count (n) =5475. The red line is the fitted curve.

3.2 Active Layer Thickness

The active layer is the top layer that freezes in winter and thaws in summer over permafrost (Zhang et al., 2005). We observed the active layer thickness (ALT) according to the maximum seasonal penetration of the 0 °C isotherm (e.g. Brown et al., 2000; Frauenfeld et al., 2004; Mackay, 1995). And kriging methods were used at interpolating the temperature values to obtain the 0 °C isotherm. Figure 5 presents the shape of the active layer bottom or the permafrost table from 2012 to 2014 based on 60 boreholes temperature measurements. At site A, the ALT ranged from a maximum of 254cm to a minimum of 136 cm with a standard deviation (SD) of 31.1 cm from April, 2012 to April, 2014. At site B, from April, 2012 to April, 2014, the maximum and minimum ALT from 15 borehole were 259.7 cm and 181.2 cm with a SD of 19.3 cm. At site 3, the variation value is 64 cm with maximum and minimum ALT of 249.0 cm and 185 cm, respectively, and the SD is 17.4 cm. Over the same period, ALT at site 4 varied from 225 cm to 290 cm with a SD of 15.3 cm. Although there are value differences between every borehole, generally, the ALT at site 1 is thinnest, followed by site 2, 3, and 4, ordinally. The vegetation coverage is similar between sites 1 and 2, however, the ALT is difference. This suggests that the vegetation may not be the main factor influencing the ALT in the study area.

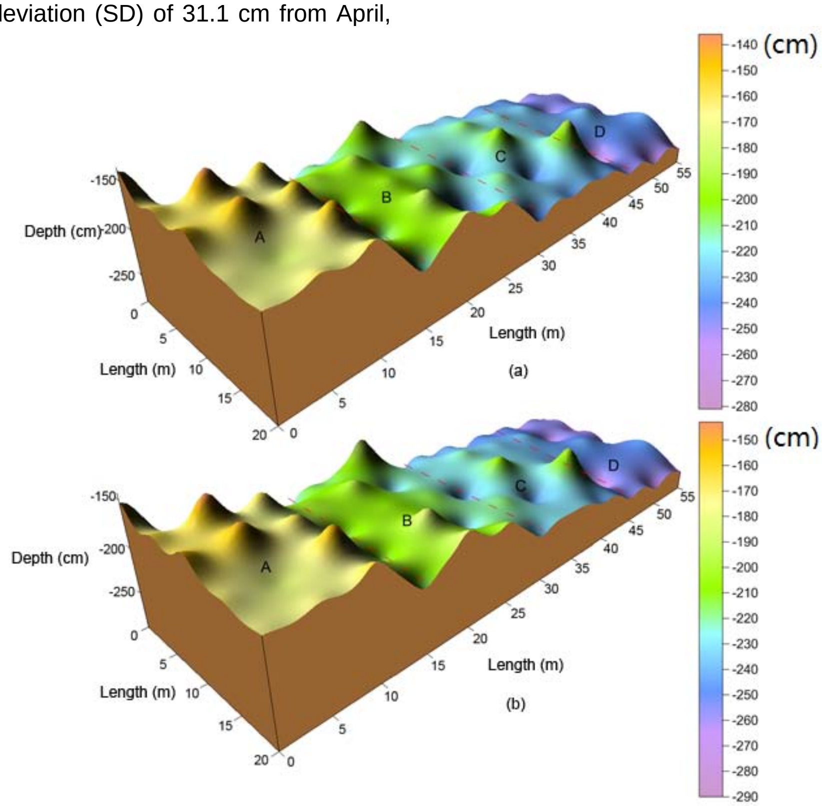

Figure 5. Shape of the active layer bottom according to the temperature measurements from 60 boreholes during study period. The kriging methods were used at interpolating the temperature values; (a) April, 2012- April, 2013; (b) April, 2013-April, 2014.

4 DISCUSSION

4.1 Air Temperature Change

It is useful to first describe some climatological characteristics of the study area (Wudaoliang Basin). The study area is about 200m^2, and we think that the air temperature is similar for the four sites. Figure 6 shows that the daily mean air temperature (DMAT) changes regularly and can be simulated by equation 1:

T_a=-4.5+12.5cos (2πt /τ -3.45)……………………… [1]

where T_a is the air temperature, t is the time (days) and π is the period which is equivalent to one year (365 days).

The air temperature change during the study period is not the main factor that we need to take into account for our analysis so that the four sites were under similar climate conditions.

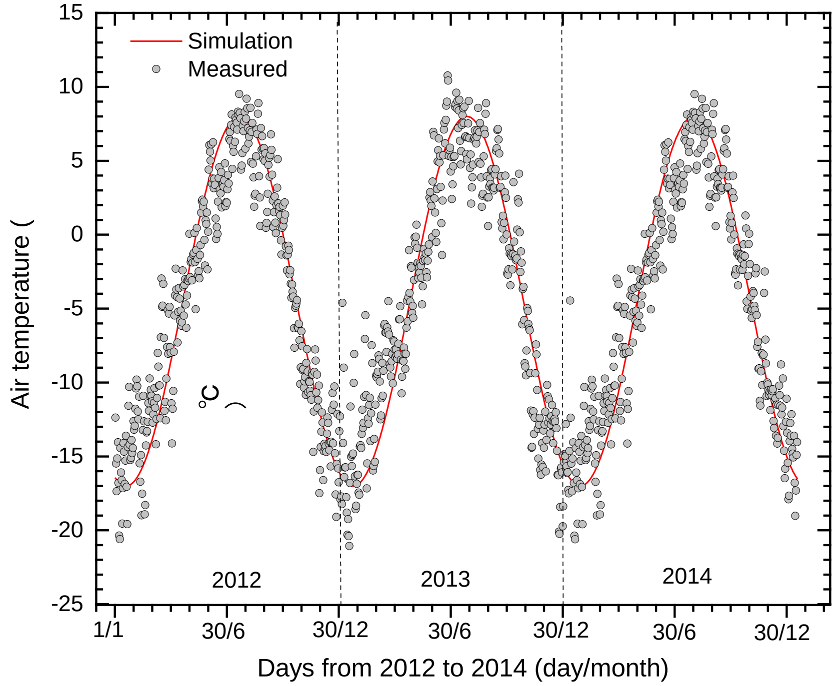

Figure 6. The daily mean air temperature (MAT) measured from the weather station. R^2 = 0.95.

4.2 Environmental Variables

The soil surface temperature (T_s) is a significant parameter for permafrost modeling (Zhang et al., 2008) and evaluating thermal regime (e.g. n-factors, thermal offset). In the study area, site 1 and site B are covered by similar dense meadow, however, the annual T_s at site 2 is warmer than site 1 (except 2013). There is little snow in Wudaoliang area or the snow cover just kept several days. The rock in site A may influence the surface thermal regime. Aeolian processes are active in Wudaoliang Basin (Lin et al., 2015). According to weather station, the northwest wind speed could reach a maximum of 16.1 m/s. From the Figure 2b, we can observe that there are a lot of grooves in site 1 and 2, and little vegetation in them. We infer that they were formed by wind erosion and they are the one of factors influencing the ground surface thermal regime. Further, we believe that with the eolian processes, the site 1 and 2 (meadow area) are under degeneration condition towards the landform of site 4 (grassland area).

4.3 Soil Water Loss

Soil moisture storage in the active layer is a key variable in comprehending most ecological process interactions (Boike et al., 1998; Romanovsky et al., 2002). Ice-rich permafrost maintains wet surficial soils, which prevents the soil moisture to percolate to deeper groundwater zone (Yoshikawa and Hinzman, 2003).

From the Figure 7, we found that the soil was much dry closer to the surface, especially at site 3 and 4. Soil water content measurement from 2012 to 2014 (except site 2 because of equipment failure) could confirmed it (soil water content at site 3 and 4 < 0.1). Figure 7 indicated that the soil moisture content increased with the depth and it was more obvious in site 1. At site 1, from 2012 to 2014, the soil water content is decreasing from 0.45 to 0.2 at 1.5m, 0.25 to 0.1 at 1.0m and 0.15 to 0.1 at 0.5m, respectively. At the same time, near site 1 and 2, there are several thermokarst lakes (Figure 2a). So these phenomenon may suggest that the liquid water is losing especially in deeper depth at site 1 (Meadow area) and the permafrost is under a degeneration condition.

Several thermokarst lakes are developing in the study area, implying that the permafrost is thawing. Thawing destroys the physical foundation (ice-rich soil) on which alpine meadow ecosystems rest causing dramatic changes in the ecosystem (Osterkamp et al., 2000). As permafrost becomes thinner or decreases in areal extent, the interaction of surface and sub-permafrost groundwater processes becomes more important (Woo, 1986). With soil water content decreasing in site 1, the surface soils are becoming quite dry as the site 4. Intensive evaporation and vertical percolation are not restricted, impacting ecosystem dynamics. These processes make great contribution to desertization. In response to some disturbance, such as human activities or climatic warming, permafrost may differentially thaw, creating irregular surface topography with the strong wind erosion. These processes are effected mutually, and the impacts are full of uncertainties.

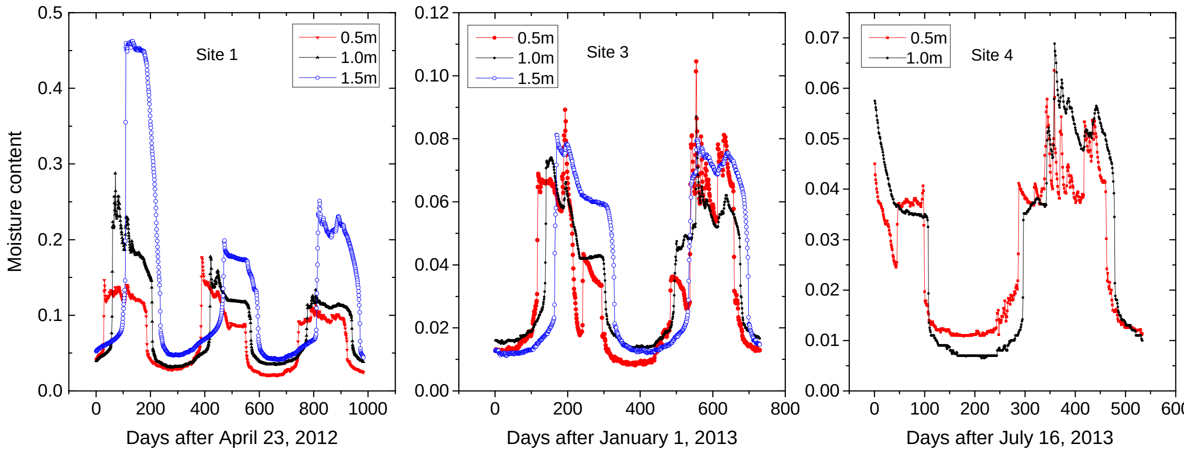

Figure 7. Daily mean soil moisture content at site 1, 3 and4 during study period. The Soil Moisture Smart Sensors were installed at 0.5, 1.0 and 1.5m depth. There were no data in site B because of equipment failure and the sensor of 1.5m at site 4 is out of operation.

5 CONCLUSIONS

With detailed field observations and more data analysis, we have a more objective understanding of the local factors, such as topography, soil water content and wind effect on permafrost in Wudaoliang Basin.

(1) At the study sites, under the similar climate condition, differences of the ground temperatures between boreholes are obvious, especially closer to the surface. The maximum variation at the ground surface reached 2.4°C at site 1, 2.6 °C at site 2, 3.0 °C at site 3, and 3.1 °C at site 4, respectively. The ground surface conditions influence the ALT, there is a maximum deviation of 118 cm at site 1, 78 cm at site 2, 64 cm site 3 and 65 cm site 4.

(2) Strong wind, soil water loss, vegetation degeneration, and thermokarst impact on permafrost existence, but the magnitude of these effects remain highly uncertain. The observations indicate that the permafrost is thawing under meadow ground. Thicker active layers could provide early signal of climate change in Wudaoliang Basin.

(3) Proper scale of the study area, factors influencing the deviation and the measuring methods need more studies in that at regional scale, macro-scale proxy data may generalize, however, local may be difficult to regionalize. Deviations will reduce the veracity of permafrost models for mapping at both the regional and local scale. Uncertainty makes assessing permafrost spatial distribution in local region difficult. A better and extensive observation is needed so that the magnitude of potential permafrost and ecological change can be better assessed.

ACKNOWLEDGEMENTS

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