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Changes in active-layer thickness and near-surface permafrost between 2002 and 2012 in alpine ecosystems, Qinghai–Xizang (Tibet) Plateau, China

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ABSTRACT

Between 2002 and 2012, daily soil temperature measurements were made at 10 sites within five alpine ecosystems in the Beiluhe area of the central Qinghai–Tibet Plateau. Changes in freeze–thaw occurrence, active-layer thickness and near-surface permafrost temperature in barren, desert grassland, alpine steppe and alpine meadow ecosystems indicate that alpine ecosystems are sensitive to climate variability. During this time, the average onset of spring thawing at 50-cm depth advanced by at least 16 days in all but the barren alpine settings, and the duration of thaw increased by at least 14 days for all but the desert grassland and barren ecosystems. All sites showed an increase in active-layer thickness (ALT) and near-surface permafrost temperature: the average increase of ALT was ~4.26 cm/a and the average increase in permafrost temperatures at 6 m and 10 m depths were, respectively, ~0.13 °C and ~0.14 °C. No apparent trend in mean annual air temperature was detected at the Beiluhe weather station. However, an increasing trend in precipitation was measured. This suggests that the primary control on the ALT increase was an increase in summer rainfall and the primary control on increasing permafrost temperature was probably the combined effects of increasing rainfall and the asymmetrical seasonal changes in subsurface soil temperatures.

1. Introduction

Permafrost is a component of a complex geo-ecological system with both positive and negative feedbacks to the climate systems (Cheng, 2004; Shur and Jorgenson, 2007). For example, based on patterns of permafrost formation and degradation in relation to climate and ecosystems, permafrost can be divided into “climate-driven”, “climate-driven, ecosystem-modified”, “climate-driven, ecosystem-protected”, and “ecosystem-driven” and “ecosystem-protected” permafrost (Shur and Jorgenson, 2007). This classification reflects the different responses of permafrost to climate change in different ecosystems. Recent ecological research has examined the impacts of permafrost thawing and ALT change on permafrost ecosystems (Callaghan and Jonasson, 1995; Jorgenson et al., 2001; Cheng and Wu, 2007; Shur and Jorgenson, 2007; Gregory et al., 2012; Wang et al., 2012); however, there has been little focus on variations of ALT and the thermal state of permafrost (TSP) in different ecosystems.

On the Qinghai–Tibet Plateau, permafrost degradation and its impact on the ecology, hydrology, and engineering are well documented (Cheng and Wu, 2007; Jin et al., 2008; Li et al., 2008; Yang et al., 2010; Wu et al., 2012, 2013). It appears that both TSP and ALT have changed greatly during the past decade (Wu and Zhang, 2008, 2010; Li et al., 2012; Wu et al., 2012). This can lead to instability of slopes and thermokarst (Wei et al., 2006; Lin et al., 2010; Niu et al., 2011), and could affect the Qinghai–Tibet Railway stability (Niu et al., 2005, 2012). Furthermore, permafrost degradation may potentially lead to reductions in both soil moisture and nutrient content, resulting in vegetation degradation and possible desertification (Jin et al., 2000; Wang et al., 2000, 2006).

The nature of specific ecosystems plays an important role in the response of TSP and ALT to climate change. Accordingly, this article describes soil temperatures measured in barren, desert grassland, alpine steppe, and alpine meadow ecosystems in the Beiluhe region, Qinghai–

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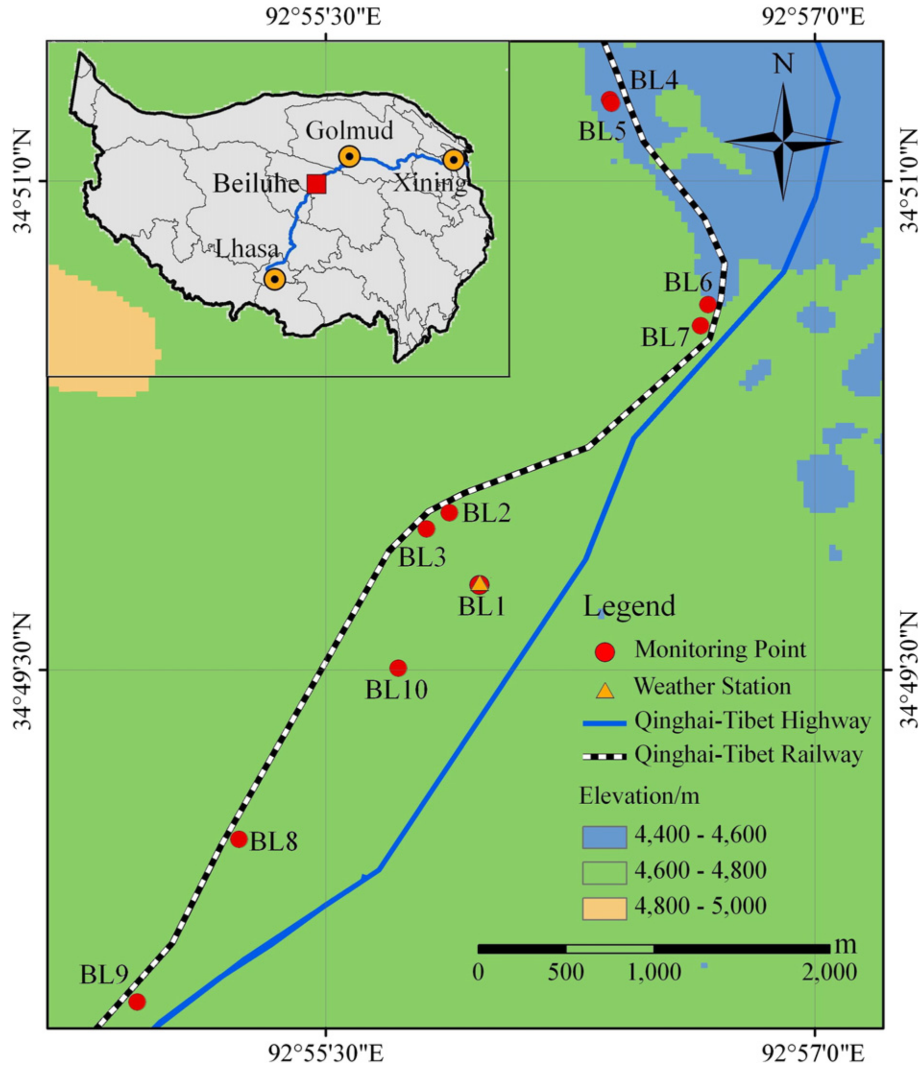

Fig. 1. Location of monitoring sites and the Beiluhe weather station (BL1 site, triangle).

Tibet Plateau, between 2002 and 2012. The aims are to (1) examine the different responses of near-surface permafrost temperature and ALT to climate change and (2) better understand the ecological effects.

2. Data and methods

Daily air temperature and precipitation data were obtained from the Beiluhe automatic weather station (Qian et al., 2005). Soil temperatures were obtained from 10 monitoring sites located within different ecosystems in the Beiluhe area (Fig. 1, Table 1).

2.1. Site descriptions

The soil temperature monitoring sites were established at Beiluhe area, 320 km from Golmud (Fig. 1; Table 1). Site BL1 is located in a barren ecosystem, devoid of vegetation, where the soil consists of sandy clay with abundant gravel. Sites BL2 and BL3 are located within an alpine steppe ecosystem with 2–6% vegetation cover and sandy clay soil in the subsurface. Six sites (BL4–BL9) are located within alpine meadow ecosystems with 16–97% vegetation cover and sandy clay soil in the subsurface. Site BL10 is located within a desert grassland ecosystem with 25.3% vegetation cover and fine sand in the subsurface. High ice

Table 1
Monitoring site information from Beiluhe.

Site name	Altitude (°)	Longitude (°)	Elevation (m)	Ecosystem	Vegetation coverage (%)	ALT (m)	MAGT (°C)
BL1	34.83	92.93	4635	Barren	0.00	3.38	−0.22
BL2	34.83	92.93	4638	Alpine steppe	2.17	2.58	−0.56
BL3	34.83	92.93	4638		5.20	2.49	−0.79
BL4	34.85	92.94	4632	Degradation alpine meadow	45.50	2.16	−0.67
BL5	34.85	92.94	4629		38.23	1.97	−0.61
BL6	34.84	92.94	4642		16.75	2.09	−0.69
BL7	34.84	92.94	4632		58.75	2.86	−0.41
BL8	34.82	92.92	4654	Natural alpine meadow	79.25	1.84	−1.52
BL9	34.81	92.92	4665		97.00	1.61	−1.45
BL10	34.83	92.93	4645	Desert grassland	25.30	3.03	−0.17